Electrical Engineering

September
1940

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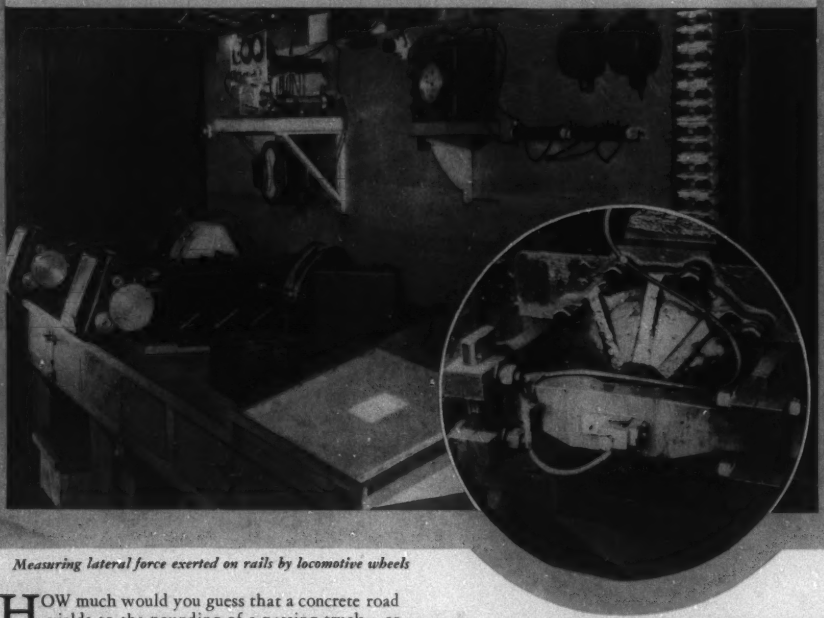
To *Measure*—STRAIN
ELECTRICALLY



Measuring lateral force exerted on rails by locomotive wheels

HOW much would you guess that a concrete road yields to the pounding of a passing truck—or the trifling weight of a boy on a bicycle? How great are the stresses set up in an airplane when it pulls out of a power dive? How much lateral force do locomotive wheels exert on the rails at 20 miles an hour; at 120 miles an hour?

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The strain gage is enabling engineers to study the behavior of bridges under higher speeds and heavier loads. Knowledge gained from studies with the strain gage helps in building better roads, lighter yet stronger airplanes, safer storage tanks, and in many other ways contributes to the progress and efficiency of industry.

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GENERAL ELECTRIC

GEI-19

A *NEW* and FASTER WAY to de-reel magnet wire

Another Belden engineering service that further reduces over-all winding costs for Belden wire users

By feeding wire from a stationary spool, instead of a revolving spool, this new Belden De-Reeler steps up output, improves the quality of finished windings, and cuts winding costs.

On fine-wire machines with revolving spools, the maximum spool weight does not exceed 3 to 5.5 lb. With a Belden De-Reeler they run from 15 to 20 lb. On heavy wire machines, the maximum weight of revolving spools is 7 to 11 lb. With a Belden De-Reeler, the spool weight is from 40 to 55 lb. One Belden wire user reports that he formerly wound 37 coils per spool change; now he runs 170 . . . a gain of 460%. Or a reduction of 78% in spool changes.

Higher Winding Speeds Now Possible

With the Belden De-Reeler you can wind coils at higher speeds because there are no loaded spools to speed up and slow down. There is no tangling when the winding machine is suddenly stopped. Wire tension remains uniform, and stretching is eliminated. The larger spools reduce the number of splices and the waste in short ends.

The Belden De-Reeler, which is adaptable to any winding machine, is essential where large, continuous production is required. Further information will be sent on request.

Belden Manufacturing Company, 4635 W. Van Buren St., Chicago, Illinois

The Belden De-Reeler and Tension Device is made in two sizes: one for No. 22 and finer; the other for heavier wires. This type of de-reeler is adaptable to any winding machine.

Larger Spools Reduce Spool Changes

Spool changes are reduced up to 78%. Revolving cap, on top of stationary spool, prevents wire from catching in damaged spool heads. Shield is raised to show large spool and cap.

"Windings per spool change stepped up 460%," says large concern

These fine-wire winding machines formerly ran 37 windings per spool change when using revolving spools. With Belden De-Reeler and Tension Devices, the use of larger spools increased the output to 170 windings per spool change.

Even Tension Prevents Tangling

Wire passes around edge of revolving cap; then goes through a guide, two dampers, and over a tensioning pulley. The cylindrical shield prevents tangling of wire at high speeds.

Belden Magnet Wires

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Back leak is an inherent property of all rectifiers. The higher the ratio of forward current to reverse current (back leak), the more efficient is the rectifier. If you were to measure the back leak of a Selenium Rectifier at a temperature of 150° F. you would find it to be less than 1/5th that of any other dry-plate rectifier.

This unique virtue of the Selenium Rectifier prevents discharge back through the rectifier should the A. C. supply be interrupted, making it ideal for battery charging and as a current-blocking device for all types of control circuits. Furthermore, the back leak always remains negligible throughout long continuous service.

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The I. T. & T. Selenium Rectifier, a 100% domestic product, finds wide, general-purpose application in a variety of forms for the rectification of large or small currents at high or low voltages. It also has many other uses, such as spark quencher, polarizer or electronic valve.

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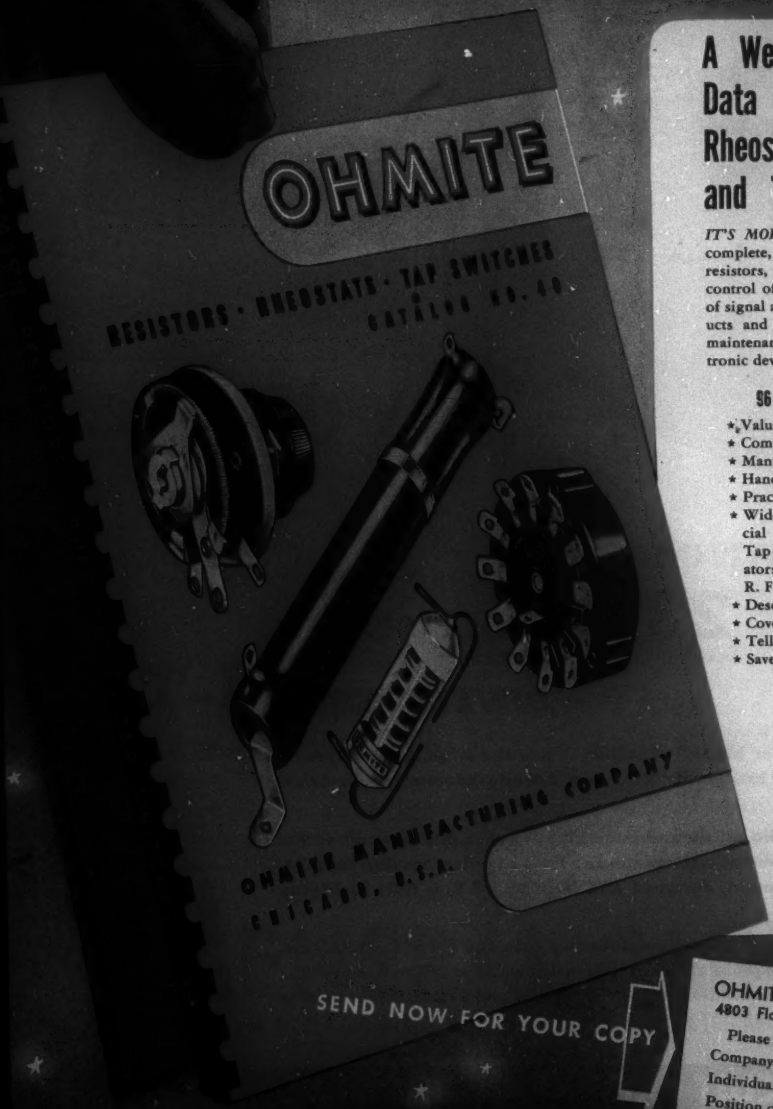

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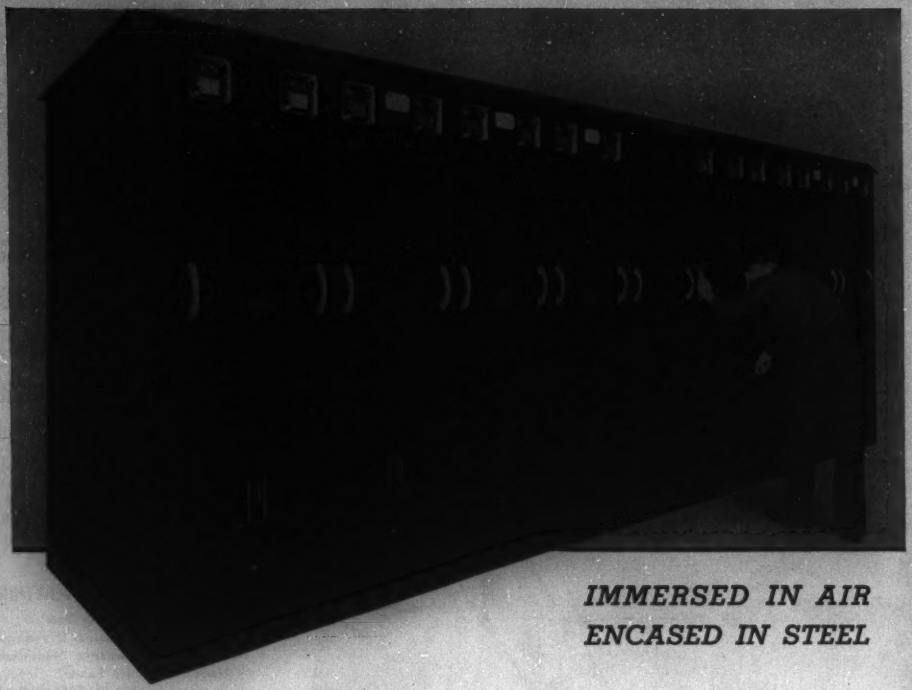

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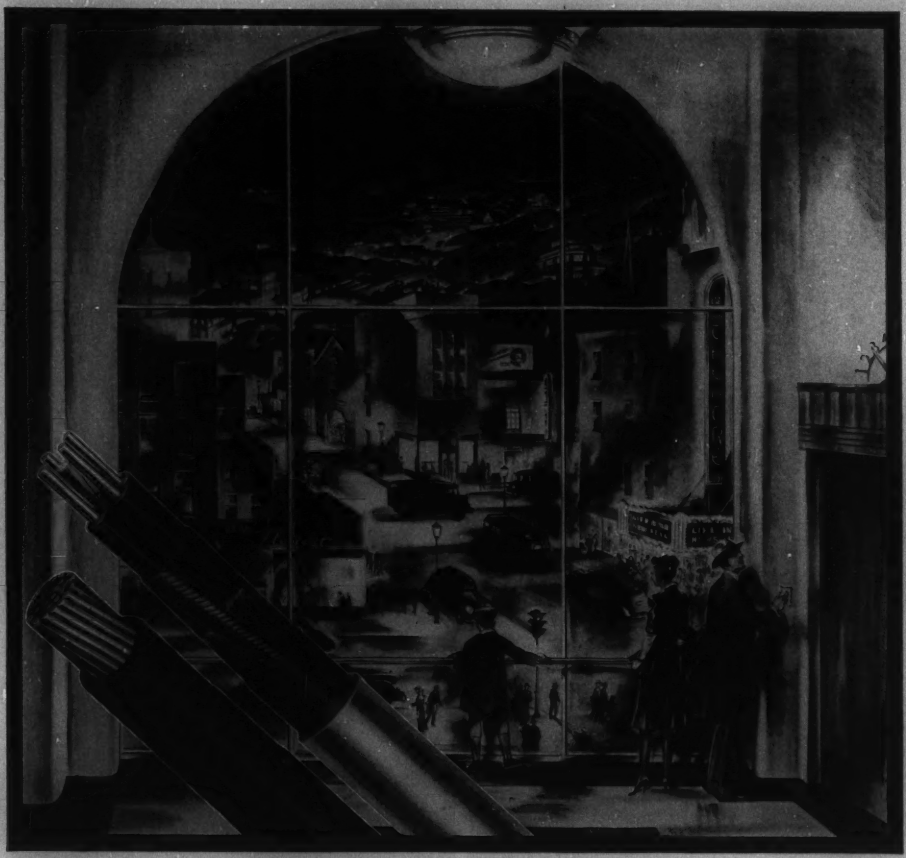

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Explaining:

The NOZZLE-SWIRL Process Of Applying LEAD SHEATH On G-E Paper-Cable

NOW, new assurance of oxide-free, long-life lead sheath that is strong throughout the length of the cable

OCCLUDED OXIDES are Enemy No. 1 of the lead sheath on paper-insulated cable.

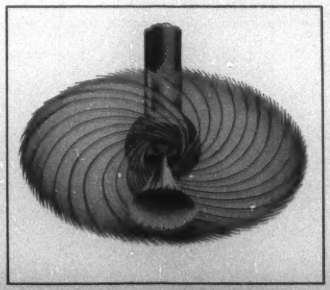
Oxidation occurs when the lead press is being charged; that is, when the lead is molten and has the greatest affinity for oxygen. Oxides also form during the extruding operation on the top surfaces of the old charge.

These facts are well known, but the problem of preventing oxidized lead from getting into cable sheath has proved extremely difficult. Here is the story of General Electric's solution of the problem.

What the Process Accomplishes

The lead-press cylinder is filled from the bottom, and the surface of the old charge is melted and scrubbed clean. Any oxides present are collected—swirled to the center of the molten lead—pulled to the surface in the form of a ball, and removed. In this way, the new charge is properly, and by every test *perfectly*, fused with the old charge.

The result is a lead sheath that is free from entrapped oxides and resultant areas of weakness, such as flow lines and laminations. It is a lead sheath that is metallurgically perfect throughout the entire length of the cable.



Showing how the lead is forced through center hole and blades of nozzle and how it is swirled by the blades

The nozzle-swirl process—in operation now for some time—has been proved successful. The secret of its success lies almost entirely in the nozzle, patented by G.E., that swirls the molten lead. Despite its apparent simplicity, this "*controlled swirling*" represents years of intensive effort on the part of our cable engineers, working in co-operation with metallurgists in our Research Laboratory. To see just how the action takes place, turn the page.

GENERAL ELECTRIC

HERE'S HOW

THE PRESS IS CHARGED WITH PURE LEAD FOR SHEATHING G-E INSULATED CABLE

BELOW is a simplified, sectional diagram of the cylinder of a lead-extrusion press. It shows the presence of oxidized surfaces and where they are located. Everything is in place for the start of the filling operation.

Note, from the illustrations on the next page, how simple the whole operation is and how it takes advantage of natural laws in removing the oxidized surfaces—resulting in a complete fusion of the old charge and the new charge.

COLOR CHART The colors are not actual and are used only for clarification.

OXIDIZED LEAD PURE LEAD

1. Oxides on Old Charge

There is an oxidized layer on the entire top surface of the old charge of lead.

2. Oxides on Shim

There is an oxidized layer, left from the preceding charge, on the entire surface of the lead shim on the cylinder wall.

3. Filling Spout

The spout is swung into the cylinder. The nozzle goes to the bottom and almost—but not quite—touches the surface of the old charge.

4. Hydrogen Flame

Hydrogen coming from jets in both the ring and the pan forms a complete oxygen-absorbing blanket of burning hydrogen.

5. Flood Ring

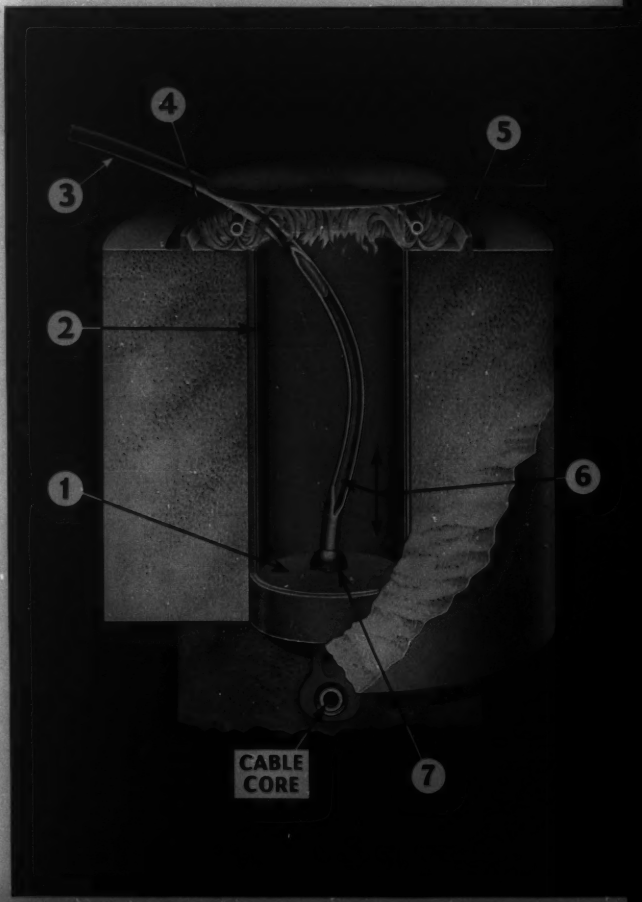
The flood ring receives the molten lead that overflows after the cylinder is full. This serves to crop the charge of lead, like any good casting practice requires the "cropping" of an ingot.

6. Inert Gas

The first real step in the process is the forcing of inert gas through the filling spout. This completely fills the cylinder and purges it of air, the agent that oxidizes the molten lead.

7. Nozzle That Swirls the Lead

The molten lead immediately follows the inert gas into the cylinder. Then things begin to happen. The streams of lead, forced through the nozzle under pressure, hit the surface of the old charge and melt off all oxides. The stream from the center hole melts the old charge directly under the nozzle, while the streams from the nozzle blades melt all the remaining areas and start the molten lead swirling. This swirling motion forces the oxides to the center where they collect on the surface and rise to the top of the new charge.

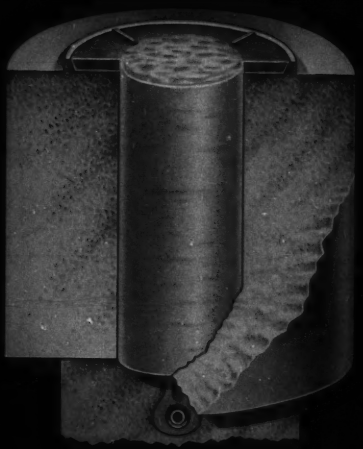


A

The molten lead has already penetrated into the old charge. The centripetal action of the swirling lead causes the oxides to collect in the center, where they are starting to form into a ball.

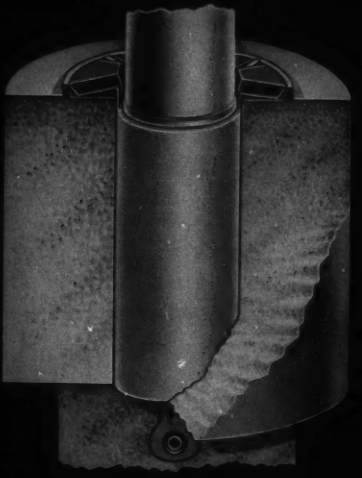
B

The lead continues to swirl, removing the entire shim, pulling all oxides to the center, and uniting them with the ball already formed. Note how the new charge has now completely fused with the old charge.



C

The cylinder is filled. The lead is still molten, and the top portion of the charge containing the oxides has overflowed and is being held by the flood ring. The ball of oxides has been removed with a ladle, and the surface has been skimmed, leaving a bright area of clean lead where the ram will enter the charge.



D

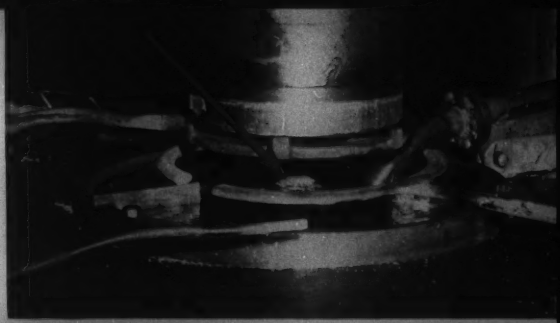
The lead is now solidifying, and the ram has begun "packing" the charge. Note how the design of the flood ring facilitates removal of the overflowed lead. When the lead has been cooled to the proper temperature, the ram will force the semiplastic lead through the die block, thus forming the lead sheath—just like a pipe—around the cable core.

GENERAL ELECTRIC

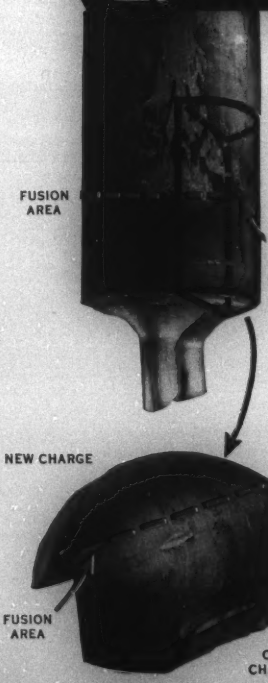
PROOF THAT THE NOZZLE-SWIRL PROCESS PRODUCES OXIDE-FREE LEAD SHEATH

1. COLLECTS OXIDES IN BALL ON SURFACE

THIS unretouched photograph shows the swirling surface of the molten lead in the flood ring on top of the G-E lead-press cylinder. The hydrogen flame has been turned off. In a moment, the hydrogen apparatus will be swung aside, the spout removed, and the ball of oxidized lead scooped out and the surface thoroughly skimmed. Then the ram will be lowered and the "packing" will be started and continued until the lead has been cooled to the proper temperature.



2. FUSES NEW CHARGE WITH OLD CHARGE



AT THE left is an unretouched photograph of a whole slug of lead taken from the cylinder. The size of the slug is 11 inches in diameter and 36 inches long. From this slug was cut the section outlined in green. This section of the slug was supported at each end in a testing machine, and then force was applied to bend the section at the area of fusion. The results of this severe test are shown in the photograph at the lower left. The lead was bent back on itself (some 150 degrees) and showed no sign of separation.

3. ASSURES PERFECT WELDS

WITH clean, oxide-free lead being delivered at these two points in the die block, and with correct pressure and temperature maintained, the complete fusion of the two streams of lead *must*—and *does*—take place.

Thus, the quality of lead sheath on G-E paper-insulated cable is uniform over the entire length of the cable. The sheath is homogeneous throughout, free from entrapped oxides, and resultant areas of weakness. It is metallurgically perfect.

GENERAL ELECTRIC COMPANY
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Electrical Engineering

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for September 1940—

The Cover: World's longest pontoon bridge (1¼ miles) across Lake Washington near Seattle is lighted with 10,000-lumen sodium lamps. Photo courtesy General Electric

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¶ Correspondence is invited on all controversial matters.

Charles Felton Scott

Engineer, Educator, Co-ordinator

NOT OFTEN in any profession, or in any generation, does there appear a man who follows youthful pioneering achievement by half a century of truly significant work; one who, having distinguished himself as inventor and engineer, displays equal ability as organizer and teacher. The life and work of Charles Felton Scott stand to prove that the combination can exist. One of the group of "great engineers" of the 90s, he was for 22 years (1911–33) head of the electrical engineering department of a great university, and at the age of 75 is still contributing vitally to the development of engineering as a profession. In the pattern of his rich accomplishment certain motifs recur consistently: the ability to perceive relationships, belief in co-operation, and a gift for applying the same simple scientific methods to the solution of whatever problems he encounters. One of the few surviving power-age pioneers, he is today perhaps more widely honored and more genuinely beloved than any other man in his profession.

Charles F. Scott was born in Athens County, Ohio, September 19, 1864. His father, William H. Scott, was professor of Greek and later president of Ohio University at Athens, where the son took preparatory training and the first two years of his college course. Entering Ohio State University at Columbus at the beginning of his junior year, Scott graduated with a bachelor of arts degree in 1885. He had a year and a half of postgraduate work at Johns Hopkins University, at the same time teaching in the apprentice school of the Baltimore and Ohio Railroad, and was then employed for a time by a company that was installing an a-c lighting plant in the Baldwin Locomotive Works.

THE WESTINGHOUSE PERIOD

In 1888 began the connection with the Westinghouse Electric and Manufacturing Company that represents one of the three important aspects of Scott's versatile life—his technical engineering career. He started as night assistant in the testing room. University graduates in the electrical industry in those days were likely to begin by sweeping floors and oiling dynamos, but for the young engineer who could endure the unpromising apprenticeship there were opportunities in the rapidly developing industry that make the more dignified course of today's graduates seem dull in contrast. Within a short time Scott was working under Nicola Tesla on the development of the polyphase induction motor, which was patented in 1888. When Tesla left the company, Scott continued the work, doing much to make practical the motor for which its inventor had supplied the fundamental theory, and carrying on other important activity connected with the development of alternating current. He became assistant electrician in 1891, chief electrician in 1897, and in 1904 consulting engineer.

The early years of Scott's connection with the Westinghouse company covered a most dramatic period in the history of the industry. Alternating current, for which Westinghouse had the United States patent rights, was being developed; high-voltage power transmission was beginning; and the Niagara power project, a milestone in the progress of both, was being planned and built. Scott was one of the brilliant young engineers who were making electrical history at a rate that seems scarcely credible to the modern world that is built on their achievements.

In the history of "Niagara Power", Edward D. Adams wrote: "The reputations of the Westinghouse engineers, Stillwell, Shallenberger, Lamme, Scott, and others . . . impressed the Niagara management with the seriousness and skill of the efforts that would be made to produce the electrical machines desired, although absolutely novel in design and unique in magnitude."[1] As consulting electrical engineer on the Niagara project, Scott "acted in an advisory capacity in many important ways".[1] His great contribution was the "Scott connection," or "T connection", by which two-phase current from the generators was transformed to three-phase for transmission. He proposed its use at Niagara shortly after the Westinghouse company had secured the contract that marked an important milestone in the development of modern electric power.

The invention of the "T connection", Scott's best-known technical achievement, occurred two years before it was used in the Niagara installation. The circumstances have been described by L. B. Stillwell:

"In 1892 I was preparing plans and estimates as the basis for a tender by the company covering the transmission of several thousand kilowatts from Folsom, Calif., to Sacramento. I knew that the General Electric Company would figure on three-phase transmission, which meant three instead of four conductors and involved a difference of $12,000 in cost of copper for the transmission circuit. I called in Scott and showed him the situation. We discussed it briefly and he expressed the opinion that the problem could be solved. Then he withdrew to another office, and within a remarkably short time returned with his two-phase three-phase connection of transformers—a perfect solution. In the light of present-day knowledge this may not seem remarkable, but in 1892 few were competent to deal promptly with problems of this type, and the incident illustrates admirably Scott's ability in applying theory to practical problems."[5]

The portrait on the facing page is by Esther Vance, New Haven, Conn.

1. For all numbered references, see list at end of article.

The same sort of ability and the same direct approach and simple methods have characterized Scott throughout his life, whether he was solving technical problems, teaching students, or getting men and organizations to co-operate for objects of which the value was generally admitted but the achievement considered impossible. In every field of his activity, he has been able to see the essentials of a problem, recognize the simplest method of solving it, and co-ordinate the means available toward the solution.

Scott's first patent, a joint one for a lightning arrester, was taken out in 1892. It was followed by more than 50 others of which the majority related to power transmission and distribution, although the scope of his interests is attested by scattered patents on other aspects of the industry. Power transmission, however, was his particular concern for many years. He contributed in 1892 the first AIEE paper on high-voltage transmission, a description of the system he had designed and installed at Telluride, Colo., a pioneer installation unique for its time. It used 3,000 volts single phase and transmitted 100 horsepower for three miles. Scott was associated with other early transmission projects, and was chairman of the power transmission section of the International Electrical Congress, held in St. Louis, Mo., in 1904.

In his work with transformers, he was the first to apply water cooling. With R. D. Mershon, he was the first to measure the power loss caused by corona. He did important work in connection with early railway electrification, including studies of means for reducing inductive disturbance on communication circuits and the development of an effective "balanced plan" for supplying power to railroads.

Scott's technical achievements during his "Westinghouse period" would in themselves be enough to insure his fame. In addition, however, he was contributing effectively to the development of the professional aspects of engineering, especially through his leadership in the Institute. At the same time, his interest in engineering education was beginning to take shape. His career as an educator really began with the training of young men in the Westinghouse company, and the student training courses that are an important part of the company's program today are the logical outgrowth of his early work. In 1902 he founded the Westinghouse Electric Club, for the purpose of providing lectures, conferences, and advanced study for the young engineers in the company, and two years later established the *Electric Journal*, primarily to preserve for successive groups the lectures given at the Club's meetings. He was chairman of the publication committee until he left the company. The magazine's first editor, paying tribute 30 years later to his "guidance, experience, and inspiration",[7] also points out that although, "by training and position an engineer, in disposition Doctor Scott has always been an educator."

PROFESSOR OF ELECTRICAL ENGINEERING

The opportunity to devote himself primarily to education came in 1911, at the Sheffield Scientific School of Yale University. There, the electrical-engineering course, until then under the department of physics, was growing in importance. "The belief that the time had come to place it on a more distinctly engineering basis (without interfering with training in the fundamental sciences) led to the creation of the chair of electrical engineering to which Scott was called. He was chosen as a recognized authority, known especially through his study of alternating current in the transmission and utilization of power, and also because of his extensive connection with the training of apprentices at the Westinghouse company."[2]

When he went to Yale there was no laboratory for electrical engineering, but "Scott's presence, and the desire of the university to utilize fully all he could offer to graduates and undergraduates made it necessary to secure as speedily as possible needed facilities for expansion of experimental work in the electrical field."[2] The result was the Dunham Laboratory of Electrical Engineering, gift of A. C. Dunham, president of the Hartford Electric Light Company, which was ready for use in 1913. When the building that now houses the electrical-engineering department was designed, Scott counseled flexibility to meet possible future conditions. The developments of subsequent years have justified his foresight in a number of instances.

From 1911 until 1933, when he retired from active teaching and was made professor emeritus, Doctor Scott headed the department of electrical engineering at Yale. Of his work there one of his colleagues writes, "Professor Scott's outstanding contribution to education at Yale was in his simple approach to relatively complicated problems. He taught the student how to arrive at correct conclusions by the application of the simplest mathematics. Also deserving special mention was his correlation of mechanics, thermodynamics, and electrical engineering through illustrative problems, such as acceleration of street cars, use of flywheels in steel mills, and conduction of heat through various materials. He would direct the students' attention to the universal laws governing these different fields—usually to their considerable surprise. He deserves much credit for the simplicity and effectiveness of his method of approach."[3]

BUILDING A PROFESSION

In addition to his direct contributions to engineering education as teacher and administrator of the electrical-engineering course of a great university, Doctor Scott has made the training of engineering students a major object in the third of his spheres of activity—his service to the engineering profession. Here also, as in education and in engineering practice, his accomplishments constitute a career in themselves.

His ability, already emphasized, to reduce a problem to its essentials and suggest a simple and logical solution has been combined in his work for engineering as a profession with an active recognition of the interrelation of the work, education, and professional organization of engineers. His terms as president of the AIEE (1902–03) and of the Society for the Promotion of Engineering Education, nearly 20 years later, both marked conspicuous advances in the history of the societies, and his influence

can be detected in nearly every major move toward effective co-operation that the engineering societies have made in the past 40 years.

He became president of the AIEE in 1902, as a young man of 38, with the uncomfortable responsibility of following in office Charles P. Steinmetz. In his own words, "I acquiesced with some misgivings, as the alternatives seemed to be to continue if possible on the same level or to slump; but I had not counted on the aid and support others might give."[4] He gives his associates well-merited credit for their share in originating the program that made his presidency outstanding, but it was Scott as president who put into effect the plans outlined in his inaugural speech.

His program included: larger membership, more papers and discussions, local Sections, Student Branches, collection of data, support of the library, permanent quarters for the Institute, and co-operation with foreign engineering societies.[8]

During his presidency, membership increased more than 50 per cent. With the first systematic plan for local activities to be put into effect by any national engineering society, local Sections, of which a few were already in existence, began to sprout rapidly, accounting for much of the increase in membership.

The idea of inaugurating Student Branches in the colleges, to give students "an insight into the problems and practices of the profession, without waiting for a sudden plunge from theory to practice on graduation", arose, according to Doctor Scott's account, from a discussion of the rate at which the electrical industry was developing. It was then doubling every five years, and Scott was struck with the need for trained men that would arise if the curve continued to mount. "I had taken it for granted that the Institute was to promote the arts and sciences relating to the utilization of electricity through adding to knowledge. . . . Should not the Institute develop men was well as ideas?"[4] The idea appealed at once to the colleges and Student Branches began.

One way of realizing the objectives of more papers and discussions and collection of data was found in Scott's appointment, at the suggestion of R. D. Mershon, of the high-voltage transmission committee, the Institute's first technical committee.

PROPHET OF CO-OPERATION

The objectives of supporting a library and finding permanent quarters for the AIEE were soon to be merged in a broader program, when Scott began to consider co-operation on a large scale among the four national engineering societies. Toward the end of 1902 he made a speech on "The Engineer of the 20th Century",[4] in which he made certain predictions. These seem startlingly prophetic today—until a look at the record shows how great a part Scott himself has played in bringing about their fulfillment.

Inspired by the establishment of the John Fritz Medal as the first joint project of the engineering societies, he predicted a building for all the engineering societies, an "engineering congress . . . representing all the engineering professions and supported by the great union of national engineering societies", and a great national network of engineering organizations, connected in national and local groups.

The Institute's library dinner, early in 1903, gave him an opportunity to suggest the idea of a joint engineering-societies building to Andrew Carnegie, who had rejected an earlier request for funds for an AIEE building. Carnegie was interested, and when Scott and others presented definite plans, gave the funds for the building. As chairman of the building committee Scott had the difficult task of achieving in practice the co-operation in which he believed so heartily. His accomplishment is attested by the Engineering Societies Building, dedicated in 1907, and managed by United Engineering Trustees, Inc., in which the national societies of civil, mining and metallurgical, mechanical, and electrical engineers are jointly represented.

The organization necessary to operate the Engineering Societies Building was given a charter that enables it not only to administer the building but to handle funds for the advancement of engineering. When in 1914 Ambrose Swasey was considering the establishment of a fund for engineering research, Scott called his attention to the latter provision. Thus Engineering Foundation, co-operative research agency, was set up as a function of United Engineering Trustees, Inc.

The "engineering congress" predicted in 1902 has been approximated by the formation of American Engineering Council, a joint agency which provides engineering and allied interests with a voice in public affairs. It came about as a result of the need for engineering counsel when the United States entered the World War in 1917. The organization set up at that time was reorganized after the war, with Scott as an AIEE member of the committee selected to plan its future. He served on the Council's administrative board from 1921 to 1933.

The fulfillment of the third part of the 1902 prophecy may be seen in the variety of projects in which national engineering, scientific, and other societies work together today, and in the many state and local engineering organizations in which local Sections representing all branches of the profession are united. Considering his widespread influence, through the AIEE and other organizations, it is probable that Scott's reiterated urging of co-operation has had no small part in bringing about the climate of opinion in which it has thus flourished.

An obvious medium for Doctor Scott's interests and talents was the Society for the Promotion of Engineering Education, which sought him as president in 1921. He demurred at first, feeling himself too busy to undertake the work, but having accepted the position, galvanized into effective action a body which he described at the time as "ponderous and topheavy".[9] Again he urged local activity, repeating the pattern he had instigated in the AIEE and which had been followed in the formation of local Sections by all the engineering societies; and again he secured results. Recognizing that the function of the SPEE must be "to develop leaders who can train engineers", he drove home the idea at meetings of the

society and in its publication, endeavoring to draw from the members ideas as to how it could best perform that function. At his instigation a development committee was appointed, on which he served, and which recommended the appointment of a board of investigation and co-ordination, to make a comprehensive study of engineering education in the United States and other countries.

Turning his attention to financing the proposed survey, Doctor Scott secured funds from the Carnegie Foundation and other sources, including the Engineering Foundation and engineering societies. Doctor William E. Wickenden, now president of the Case School of Applied Science, was director of the survey, and Doctor Scott chairman of its supervising board. Five years of fact-finding, seven seasons of summer-school sessions for engineering teachers, and two European trips by the director culminated in a comprehensive report, the first volume of which was published in 1930 and the second in 1933.[8] The findings of the survey provided a basis on which engineering education could be evaluated and its future intelligently planned. Doctor Scott's contributions are suggested indirectly in his report as chairman, published with the findings of the investigation, in which he says, "What engineering education must have is a guiding philosophy based on a clearer visualization of the place of engineering in modern life."[8]

One of the conclusions reached in connection with the survey was that the development of engineering education in the directions suggested by the survey findings could best be achieved by the co-operation of the schools under the guidance of a central body. The findings of another survey, a study of the economic status of the engineer made by The American Society of Mechanical Engineers during the early 1930s, pointed in the same direction. The result was the formation in 1932 of the Engineers' Council for Professional Development, on which the national societies of civil, chemical, electrical, mechanical, and mining and metallurgical engineers, the SPEE, and the National Council of State Boards of Engineering Examiners are represented, and of which United Engineering Trustees, Inc., is treasurer. Doctor Scott has been active in ECPD since its organization, served as its chairman 1935–38, and is now chairman of its committee on professional recognition, and a member of its executive committee. The organization is the embodiment of his belief that "the development of the young engineer is the joint responsibility of the schools, the professional societies, and the registration boards."[10]

Doctor Scott might seem to have taken his own full share of that "joint responsibility," through his work at Yale and in the societies; since 1935 however, he has been active also in engineering registration, as chairman of the Connecticut State Board of Examiners and a member of the National Council of State Boards of Engineering Examiners. He represents the latter body on ECPD, was vice-president 1937–38, and since 1938 has been its president.

Along with his many other duties and activities, Doctor Scott has had a record of continuous service in the AIEE that has been equaled by few other members, and by none now living. He joined the Institute in 1892, transferred to Member grade in 1893, and to Fellow in 1925. He has been a manager (1895–98), vice-president (1899–1901), president (1902–03); member at various times of many of the Institute's committees and Institute representative on many other organizations. At present he is a member of the committee on Student Branches and Institute representative on the Thomas Alva Edison Foundation. He was one of the founders and the first chairman (1921–22) of the Connecticut Section, and was also founder of the Yale Student Branch. In 1929 he was made an Honorary Member, and was awarded the Edison Medal, the highest Institute honor, for that year, with the citation "for his contributions to the science and art of polyphase transmission of electric energy." In 1930 he was awarded the Lamme Medal of the Society for the Promotion of Engineering Education, which is conferred "for accomplishment in technical teaching or actual advancement of the art of technical training."

The degree of master of arts was conferred on him by Yale University in 1911, and he has received four honorary doctor's degrees: doctor of science from the University of Pittsburgh in 1912 and from Ohio State University in 1937; doctor of engineering from Stevens Institute of Technology in 1912 and from the Polytechnic Institute of Brooklyn in 1935. In addition to the various society affiliations already discussed, he is a member of The American Society of Mechanical Engineers, the Engineers' Society of Western Pennsylvania, of which he was president in 1902, the Illuminating Engineering Society, American Philosophical Society, Sigma Xi, Tau Beta Pi, and an honorary member of the Connecticut Society of Civil Engineers.

"DIAMOND JUBILEE"

In recognition of Doctor Scott's lifetime of achievement, a number of special celebrations were arranged in honor of his 75th birthday, which was September 19, 1939. A testimonial dinner, sponsored by the AIEE Connecticut Section, and held in New Haven, Conn., on his birthday, was a gratifying example of the co-operation he has urged, as representatives of the American Chemical Society, American Institute of Architects, American Society of Civil Engineers, American Society of Metals, American Society of Mechanical Engineers, Connecticut Society of Civil Engineers, Kiwanis Club of New Haven, AIEE Yale Branch, and Yale University joined with the AIEE to do him honor.

During 1939 and 1940, many AIEE Student Branches have held "Scott diamond jubilee" programs in recognition of Doctor Scott's attainments and his special position as founder of Student Branches. Doctor Scott attended the first of these meetings, which was held by the Yale Branch March 17, 1939, and has attended a number of others since. At about 75 of these Branch meetings, motion pictures depicting Doctor Scott's career have been presented. In response to a request for a letter of greeting for occasions when he could not be present, Doctor Scott supplied the characteristic summary of his own career, which follows.

"My impression on seeing the film," he wrote, "was that it was a fairly true picture of the kind I have tried to make. It seemed to me that the career I was presenting was one in which many instances had a common background. I realized a situation. I saw in it a problem, a need, and after a little simple straightforward thinking, I realized that maybe something could be done about it. And I set about in a simple way to do a few little simple things, starting along a new path. The principal element in success lay in the fact that I kept at it. At least, I kept at those things which did materialize. There are many others, bygone possibilities which I have not mentioned, and many of which I have forgotten; but in the long run it is not what a man has not done, but what he has done, that really counts. Half the things that he seems to have done are due to the efforts of others who have aided in bringing about results."

REFERENCES

1. Niagara Power, **Edward Dean Adams.** The Niagara Falls Power Company, Niagara Falls, N. Y., 1927.

2. History of the Sheffield Scientific School of Yale University, **Russell H. Chittenden.** Yale University Press, New Haven, Conn., 1928.

3. Report of the Investigation of Engineering Education, 1923–29. Society for the Promotion of Engineering Education, office of the secretary, Pittsburgh, Pa., volume 1, 1930; volume 2, 1934.

4. The Institute's First Half-Century, **Charles F. Scott.** Electrical Engineering, volume 53, May 1934.

5. "Edison Medal Presented to Charles F. Scott", Journal of the AIEE, volume 49, March 1934, pages 233–4.

6. Proposed Developments of the Institute, **Charles F. Scott.** AIEE Transactions, volume 20, July–December 1902.

7. *The Electric Journal*, volume 31, February 1934, page 47.

8. Unpublished letter, H. M. Turner, Yale University, October 18, 1939.

9. *Engineering Education*, volume 12, 1921–22, page 46.

Other sources consulted include articles and addresses by Doctor Scott and others in Electrical Engineering (especially the 50th Anniversary Issue, May 1934); AIEE Transactions, volumes 20–22 (1902–03); *Electric Journal*, volumes 1 (1904) and 31 (1934); *Engineering Education*, volumes 12 and 13 (1921–23); and unpublished addresses and letters.

Some Needed Improvements in Engineering Education

A noted industrialist* points out some of the shortcomings of our present system of engineering education and suggests some needed improvements

THERE are at least five different features in our present-day technical education which are justly subject to criticism: (1) trend toward specialization in undergraduates courses; (2) lack of proper standards of selection of students to be admitted to engineering courses; (3) failure to develop in the student the habit of thorough understanding of subject matter and processes; (4) insufficient emphasis placed on development of student personality; (5) examinations and student grading which are not the true test of student ability desired by the employer. These, of course, do not each apply equally to all institutions, but can be accepted as fair criticism of the average institution.

It would seem that there is one underlying error common, at least in practice if not in theory, in most of our institutions to which these various faults may be traced. This is the failure to appreciate that the *chief objective of a technical education should be to train the student in logical thinking and develop his creative imagination; that it should be aimed primarily toward the acquisition of power rather than toward the amassing of factual knowledge.*

UNDERGRADUATE SPECIALIZATION

The trend toward following the latest educational fad of the day to the injury of sound, basic education is a serious problem in all of our engineering colleges. It is the consensus of employers of technical graduates that specialization in an undergraduate course is highly undesirable for the following reasons:

1. It takes valuable time of the students which may be employed in obtaining a more thorough understanding of, and training in, the fundamentals of engineering and their broad, rather than specialized, application. Our courses in technical colleges are already overcrowded and are in need of simplification.

2. An overcrowded curriculum leads to superficiality rather than thoroughness. Above all things, the engineer must be thorough. Thoroughness, which includes and emphasizes understanding, should be the first objective of engineering training.

3. With few exceptions, current engineering practice in special fields cannot be taught successfully to undergraduates. The newer arts are advancing with exceeding rapidity and textbooks are out of date almost before they are printed. Such courses can be taught successfully only by specialists who are practicing engineers, and, therefore, taught as lecture courses. It is much better that the student should gain his specialized knowledge in actual practice.

4. Probably more than 90 per cent of the students do not follow the field in which they have specialized when at college. Circumstances and opportunity for employment play the most important parts in the ultimate selection.

5. It adds unnecessarily to the over-all cost of running a technical college. Cost of instruction in, and operating laboratories for, specialized fields is all out of proportion to the cost of the more important fundamental instruction.

INADEQUATE STANDARDS OF ADMISSION

There exists a very subtle yet definite competition among our technical schools for either numbers or quality of students. This leads, on one hand, to putting forth undesirable undergraduate curricula as window dressing to

* Excerpts from a paper "The Employer Suggests Needed Improvements in Our System of Technical Education" by W. H. Carrier, chairman of the board, Carrier Corporation, Syracuse, N. Y., presented at the semiannual meeting of The American Society of Mechanical Engineers, Milwaukee, Wis., June 17–21, 1940.

attract students, and, on the other hand, to the admission of some students in colleges who are unqualified for an engineering course. In general there is insufficient consideration given to student aptitude and there are inadequate requirements for admission to the course of the type of ability needed in engineering.

It may be assumed that most engineering students have an interest in their work. But more than this is required: They must have natural analytical ability. This is the real criterion of whether they should go to a trade school or take an engineering course in a university.

Unfortunately, high-school standings alone cannot be taken as sound criteria of the student's analytical ability. The increase in the age of employment, combined with compulsory education, have put into our high schools large numbers who are not interested in further instruction, as well as those who have not the ability for high-school work. This necessarily lowers the standards in many of our high schools and tends to mechanize secondary education. Entrance requirements must be revised to take into consideration definitely poorer standards of secondary education. This means that the candidates should be qualified for entrance into engineering courses by a suitable minimum college entrance examination. This should partake of the "intelligence test" type of examination to test natural thinking and reasoning ability, and should be supplementary to the qualifications indicated by high-school or preparatory-school standing. Evidence of adequate training in English should be required through examination at entrance, and further training in this subject should be provided during all four years of college.

The desirable educational standard can be made possible in engineering colleges only by the selection of the ablest from a number of applicants. This may seem severe, but it must be remembered that even now there are many more engineering graduates in this country than can be absorbed profitably by industry. Industry has no use for "duds," and the preliminary sorting out could be done most soundly and economically at the engineering college.

SUBJECT MATTER VERSUS MENTAL TRAINING

As it has been pointed out, our engineering schools seem to vie with each other in publicizing extensive undergraduate curricula in which subject matter is stressed rather than training. Herein lies the cause of many of the principal defects observed by employers in our present day education. The student is expected to learn more and more in a given time and the courses must be made "easy" so he can accomplish the work laid out in the curriculum. To obtain high or even passing marks, he must memorize extensively; he cannot take time to think. The main purposes of an engineering education—a thorough understanding of principles and training in the use of the mental "tools" of the profession—are thus defeated. Training in thinking is far more important than the mere acquisition of factual knowledge. Employers want graduates trained in logical thinking, in habits of thoroughness, and in the scientific method of approach.

In engineering education, the aim should be to have no fact or theory accepted until it is first thoroughly understood. Memorizing without thorough understanding does not develop the habit of mind that is so necessary in later life to the successful engineer. On the contrary, it leads to a habit of taking things for granted, and often to a feeling of mental helplessness and inferiority fatal to mental progress in later life.

The engineer who advances the boundaries of his profession must have curiosity and an inquiring mind. These natural mental attributes should not be deadened or stultified in the process of technical education, but should be stimulated and developed. Teaching, so far as possible, should be through guidance rather than through enforced assistance. The inductive method should precede the classical, and commonly overdone, deductive method.

Furthermore, it is doubtful if our colleges today have the properly trained personnel in sufficient numbers to follow successfully any system of instruction other than that which is now so generally employed. The majority place too much dependence on slavish following of texts which are written more from the standpoint of reference books than teaching texts. Real teaching must be independent of such texts and must be individualistic with the fundamental educational aim in view. Such teaching cannot be mechanized. The text should be used primarily as a review and as a means of consolidation of what has already been taught.

Very much more time should be allotted to the mastery of the elements of a subject largely by the inductive method, and very much less time spent on the presentation of the more extensive details of the subject. Thoroughness should be aimed at rather than completeness. Besides, the lecture method of presentation is often overdone and wholly fails to accomplish the purpose for which it is intended.

To improve our methods in technical instruction, instructors must be far better trained in teaching methods and it must be recognized that such training is equally if not more important than the proper mastery of the subject itself by the instructor. There is today no adequate training in colleges for our instructors in their art. This should become a faculty duty, and must be so if we are to improve our method of education. Instructors must be taught how to teach and be imbued with the proper ideals of education. Today *we have many teachers but few educators.*

To be successful in undergraduate work, our faculties must be headed by great educators. The best educators, contrary to common practice, should be placed in charge of freshmen and sophomore classes where it is necessary to start the student on the right path, and the best talent should not be left for the junior and senior classes as at present.

DEVELOPMENT OF STUDENT PERSONALITY

There is a tendency in our schools to overemphasize the technical side of education at the expense of the human aspect. The engineer's success depends fully as much on his ability to deal successfully with human

problems as it does upon his ability to deal with mechanical problems. It has been truly stated that few engineers lose their jobs because of lack of technical ability. Jobs are lost largely because of failure in human relations.

The importance of this phase of education is becoming more appreciated in some colleges. It is usually emphasized in so-called courses of administrative engineering, but it should not be neglected in *any* technical course. It is almost as important for the success of research engineers as it is for those in executive positions.

SYSTEM OF STUDENT GRADING

Another failure of engineering schools, from the employer's standpoint, is that he finds difficulty in selecting a man on the basis of his standing in college. The employer can obtain some idea of the personality of the student from an interview, but he must rely wholly upon the college standing of the young graduate for an appraisal of his mental ability. Since today a student's standing, as evidenced by his "marks", merely indicates his application, which is valuable, and his memory ability in memorizing facts and formulas, it does not disclose, at least independently, his ability in perception and reasoning which is one of the chief characteristics in which the employer is interested.

To appraise the student better of his educational progress and to aid the employer in his judgment in the selection of engineering graduates, an entirely different system of marking must be employed. Far greater stress should be laid upon a thorough understanding of principles and their application, rather than upon factual knowledge or facility in engineering calculations.

Engineering and Research for American Defense

L. A. HAWKINS
MEMBER AIEE

An address delivered at the AIEE 1940 summer convention, Swampscott, Mass., June 24–28

NOT LONG AGO I heard an engineer, whom I regard highly, say that in his opinion engineering and research were quite similar. In spite of my great respect for his ideas, I must disagree. Research demands the willingness to try anything once, however small the chance that the result will be satisfactory. The engineer on the contrary must restrain with balanced judgment his impulses toward novelty. His profession calls for a degree of conservatism. While he should be open-minded and receptive to new ideas, he should weigh the chances before going ahead. An engineer has well said that you never know how good a design is until after you have changed it. But that same conservatism may be fatal to success in research.

The reason is that the engineer deals with relatively high degrees of certainty so that a high percentage of success is expected and required in engineering development. He who cannot attain and maintain that percentage is a poor engineer, and is likely soon to be seeking other employment. But research deals largely with unknowns, so that one hit in six to ten times at bat is a good average, and that hit may come from the most unpromising experiment of all, though in that case the result is likely to differ more from expectations than a home run differs from a bunt.

Doctor W. R. Whitney (General Electric vice-president in charge of research) has said, "Any fool can tell me why it is useless to try an experiment. I want the man who will think of new experiments to try."

Mention of Doctor Whitney reminds me that only last week I acquired a new word from him—"serendipity." It may be found in Webster's International Dictionary, but I imagine it is a stranger to many of you as it was to me a week ago, although it signifies a quality invaluable to a research man and far from valueless to an engineer. It is defined as the gift of finding useful things not sought for. It was coined by Walpole nearly 200 years ago to apply to a story he had read of "The Three Princes of Serendib" (which is another name for Ceylon) who in their travels discovered by chance or sagacity things they did not seek.

The more I think of it, the more convinced I become that a very large part of the progress of mankind has been due to serendipity. You remember Charles Lamb's essay on the origin of roast pork—a perfect example of serendipity. So must have been the genesis of glass making, of refining and tempering metal, of the mariner's compass, of the sailboat, and of countless other things. The stories of Newton's falling apple and James Watt's dancing kettle lid may be apocryphal, but they at least symbolize the eternal truth that our knowledge has advanced and our civilization developed because certain individuals had the gift of seeing gold in what to the rest of the world was common clay.

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America was discovered through serendipity. So was the planet Neptune. It was serendipity that led Galvani, Oersted, and Faraday to the discoveries on which our electrical industry was based. Serendipity in Goodyear created the rubber industry. It led Nobel to the invention of dynamite, Perkin to coal-tar dyes, and Roentgen to X rays. These are only a few of the multitudinous examples that might be cited. In the General Electric research laboratory, such things as the gas-filled lamp, the Coolidge X-ray tube, the radio power tube, the Tungar rectifier, atomic hydrogen welding, copper brazing in hydrogen, and the inductotherm arose from serendipity. Chance played its part in all of them, but it was chance operating in the presence of a keen observer. As Pasteur said: "Chance favors the mind that is prepared."

Whitney suggests that serendipity is the reaction to an observation of that store of memories, knowledge, and mental habits which we call the subconscious mind. It is a tempting thought to pursue, but I can give no more time to this subject. If you wish more, you may find it in an article by Cannon in the March *Scientific Monthly*. I have divagated too far from my comparison of research and engineering. I shall return to it with the remark that research, as an offset to its relative uncertainty which I have mentioned and as a result of the novelty of the fields it is exploring, offers far more opportunity for the exercise of serendipity than does engineering.

I am stressing the difference between engineering and research because it is most desirable that engineers and research men should fully understand each other, for understanding is essential to real co-operation, and co-operation is essential to smooth and rapid progress. Engineering and research are complementary. Each is dependent on the other. The business of engineers is to apply scientific facts for useful ends. Scientific facts are their most important raw material. Without a continuing supply, engineering progress must slow down, and the only source of that supply is research. The research man's job is to discover new facts, but without engineering applications of those facts research would be practically sterile.

So if you engineers are tempted to regard the research men you come in contact with as visionary, lacking in judgment, impractical, with no sense of values or of time, remember that you may appear to them as obstructive, moss-backed, and blind to opportunity. Also remember that they are compelled, like any other salesmen, to strive to get your point of view, for you are their customer for their stocks in trade—the new facts they have discovered and the new ideas those facts suggest—while you are under no compulsion, except the realization on your part that mutuality of understanding is demanded by the true interests of both.

I do not mean to imply that research men and engineers have been at loggerheads in the past. I have in mind only that the fullest co-operation is demanded now as never before.

Past co-operation has indeed been fruitful. American engineering, aided by research, has made the United States by far the most powerful industrially. Electrical engineering particularly has so developed the potentialities of electricity as to make it the lifeblood of our civilization, so that if the supply were suddenly cut off it would bring unparalleled catastrophe. To evoke that mighty genie, and to make it the omnipresent, ever ready, efficient, inexpensive, and indispensable servant it has become, has required engineering ability of the highest order. The AIEE may well pride itself on the magnificent record. And if research has often supplied the tools, it detracts not one bit from the credit due to engineering. Rather it is all the more to the credit of engineers that they have been quick to grasp those tools and apply them effectively. Why then should I plead for still more effective co-operation between research and engineering? It is because I foresee its need in the immediate future.

It would be delightful indeed if we could continue for another 40 years, or even for one more year, such peaceful and beneficent developments as have engaged us with only a brief interruption through the last four decades. But I see no hope that that may be. The world around us is changing most horribly for the worse, and we must face about to meet that change. As citizens and as engineers we must profoundly alter our lines of thought and our activities. We must awaken from our dreams of fancied security and face the stern reality of imminent catastrophe. As citizens we must prepare for such sacrifices as we never before in our lifetimes have been called upon to endure. As engineers we must demote to a secondary place our efforts to promote the peaceful industries and must devote our minds and hearts primarily to the problems of war.

Such diversion of engineering effort to the service of the war Moloch was accomplished years ago in the totalitarian states of Europe. While we have been effectively developing the potentialities of engineering to further the industrial prosperity of the United States and the welfare of its people, in those other states those potentialities have been focused on weapons of destruction and slaughter. The result has been the creation of such a powerful war machine as the world had never seen nor dreamed of. And now that fearful machine is rolling ruthlessly forward, laying waste everything in its path, crushing out the lives of millions, enslaving one free people after another, stamping out liberty, justice, and human dignity, and forcing more and more of the world into abject subjection to cruel, intolerant despotism.

Today the British fleet is our sole remaining defense in Europe. If that passes into Hitler's hands we shall be left to face, practically singlehanded and at terrible odds, a hostile totalitarian world. Let us not delude ourselves with thoughts of the Atlantic as a barrier nor dreams of the solidarity of the western continents. If the British fleet goes, Hitler's power will extend directly to our shores. Already his fifth column is active in this hemisphere. More than one South American nation is threatened by internal disorder and possible revolution through Nazi machinations. Europe, not the United States, is the natural customer for their agricultural products. Their commercial interests tend to turn them from us to Hitler. If the British fleet goes, we may find ourselves fighting

practically singlehanded against a malignant enemy, armed to the teeth, terribly outclassing us on land, on sea, and in the air.

The Nazi war machine cannot be stopped by wishful thinking. It cannot be stopped by hastily improvised defense, however heroic. It can be stopped only by a machine more powerful than itself, and the creation of that machine is largely the task of engineers. The Nazi Juggernaut was created by engineering, and it is only by engineering that it can be destroyed. To accomplish that destruction must become our immediate prime objective, taking precedence over all other aims, even to their total exclusion if they would interfere with, or delay, its achievement.

Research too must bend all its energies to the same end. The fascinating search for truth for its own sake must be temporarily abandoned, and thought and effort concentrated on the problems of military preparedness. All our research facilities and brains should be devoted, so far as they can be so employed, to the special problems arising from military engineering developments. Research and engineering must work together as never before to the attainment of a single end.

We cannot longer afford to indulge ourselves in the luxuries of peace. All the principles, ideals, and institutions we hold most dear are threatened by ruthless aggression. They were bequeathed to us by our forefathers at the cost of blood and sacrifice. We would be recreant sons, unworthy of our great heritage, were we not quick to make all needed sacrifice to preserve it.

But what can we do, now, as individuals? How make a start on our urgent task? Before we can do effective war work in research or engineering we need many things. We need definite information on the problems of army and navy and on the present status of attempts at their solution. We need the closest kind of co-operation between government, industrial management, and labor in order that we may organize, finance, and execute the mighty task ahead. To achieve this we must first do our part as citizens, before we can play our roles as engineers or scientists.

First of all we can prepare ourselves. We can orient our thoughts away from things which have become secondary, and toward our major task and the sacrifices it demands. We can try to face the facts clear-eyed, and with minds undrugged by wishful thinking. Next, we can help others to see clearly, to cut loose from such facile optimism as recently led 500 American scientists to join in a cry to the President for peace, when there is no peace and can be none so long as brute force seeks to dominate the world. Finally, as citizens, we can help to bring pressure to bear on our governmental leaders, executive and legislative alike, to tell the people the truth, to mobilize the latent patriotism and courage of the nation, to organize the national resources, and the needed channels of information, to give American industry a chance freely to exert its mighty powers to bring preparedness plans to quick fulfillment.

Then will come our opportunity. American engineering, aided by American research, has made us industrially by far the most powerful nation in the world. We produce and use nearly one-third of all the electric energy produced in the world, and our standards of living are the envy of all other countries. That same engineering ability, backed by ever strengthening research facilities, can surely demonstrate its superiority in the arts of war as it already has in the arts of peace.

Give us our chance, and give it to us now. The monstrous Nazi machine is on its ruthless way. Already it has crushed the democracies of Western Europe. Britain alone, with her fleet, now stands between ourselves and it, and who knows how long she can endure? Give us the chance before it is too late. Americans are ready to fight and sacrifice and die for their country and their liberties, but they cannot bare-handed withstand the super tanks and bombing planes. It is we engineers who must arm them. So again we cry to our government, "give us the chance and give it now."

We, who are proud of our profession, cannot suffer that future historians shall say that it was engineering that caused the black-out of liberty, the annihilation of all that was best in our democratic civilization. Rather let it be said that, when engineering tools in the hands of brutal despots threatened the liberties of the world, it was American engineering that arose in its might and created impregnable mechanisms of defense to the end that "government of the people, by the people, and for the people" did "*not* perish from this earth."

Cincinnati, site of AIEE Middle Eastern District meeting October 9–11, is here seen from the Kentucky shore of the Ohio River

Transportation as a Social Problem

Divergent points of view as presented at a forum held jointly by the AIEE and the American Engineering Council in connection with the Institute's 57th summer convention

The Railroads Can Do Their Job

ROBERT S. HENRY

Assistant to the president, Association of American Railroads

Most of us have seen trains, but there are many, many people in the world who have never really seen a railroad, who have never seen it with their mind's eye, never caught the meaning of the thing, and never understood just what it is and does and means in the lives of all of us on this American continent. A curious sort of blind spot afflicts us toward things to which we are accustomed. We see them around us with our physical eye, but those that were here before we were, we are pretty likely to take as a matter of course—to take them for granted as we take water and air and other indispensables of life.

Really, when the railroad was born, there came into the world something totally new; not just a new way of doing things, but a new thing itself. There had been wheeled transportation long before there were railroads, of course, as far back as the history of the race runs. There had been tracks before there were railroads in the modern sense, before we began to use mechanical power on them. And there even had been mechanical power for nearly a century before we had railroads, but it was stationary mechanical power. Combine those three things—trains of cars, mechanical power, and tracks—into one operation, though, and you have created something so totally different from anything that ever existed in the world before that it remade the world.

The dramatic thing about a railroad is power—the locomotive. The essential thing is rails—the rails that guide the flanged wheels of long trains of cars, that make it possible for a hundred thousand or more freight cars to be loaded today and every day in the year at any one of the million and more track locations in the United States and Canada and Mexico, assembled into trains, and moved to destination for unloading at any other one of the track locations on this continent.

RAILROADS AND OUR NATIONAL LIFE

This combination of the flexibility and convenience of the individually loaded and unloaded freight car with the economy of mass transportation in trains between stations is the fundamental thing about railroads. It is the thing that has made possible the settlement and civilization of this continent—to the extent that it is civilized.

In England you can't get 75 miles from deep water. In the western parts of the United States, you can draw a circle 1,200 miles across that will nowhere touch water deep enough to float a boat, or water than can be made deep enough to float a boat, even with the most generous expenditure of government monies.

Our lives here have been built upon the fundamental fact of mass transportation in trains on tracks. It is a thing that could be done nowhere else, because on no other surface that can be conceived is it possible to have 50 or 100 cars follow at high speed behind one unit of motive power. Nowhere else can you even imagine that being done—although in some of the western states some truck operators seem to have ambitions in that direction.

The situation in the United States today causes us all to focus our thinking pretty much along one line: how we can get on with our belated but so necessary program of preparedness. The question which is asked of us in the railroads—the very fact that it is asked shows the degree of interest that the public is taking in it—is, what the part of railroads will be in such a program, and how ready are they to play that part?

Statistics are necessary to modern study, and the slide rule is a wonderful instrument. But even the most expert and ingenious statistician and the smoothest slipstick operator must get all his facts on the stick and get them on right before he can get the right answer. The easiest way to get the wrong answer is to start with the wrong assumption, to start without the facts. Take the widespread popular impression that the railroads broke down in 1917, and that consequently on the first day of January in 1918 they had to be taken over by the Government because of that breakdown.

CAUSES OF 1917 DIFFICULTIES

What broke down was not the railroads as transportation machines. The failure that led to that very costly experiment of Government operation during the last World War was not a failure of transportation capacity; it was a failure to use railroads as transportation machines and an attempt to use railroads and their cars as a form of storage for freight that nobody was quite ready to unload.

The best description of what happened that I know of is in the 1918 report of William G. McAdoo, the United States director-general of railroads, outlining the "potent" causes of the congestion that led up to Government operation of the railroads. The interesting thing is that, with one exception, the several points mentioned had nothing to do with railroads. The one exception according to the report, was a shortage of motive power in 1917. There may have been; I don't know and neither does anybody else, because the railroads had no opportunity to use the motive power they had in any proper way.

The significant things are the other causes Mr. McAdoo mentioned. One cause, he said, was the zeal and enthusiasm with which the various departments of the Government issued priority orders for shipment of Government freight. You understand that in time of war the railroads are bound by law to give "preference and priority" to Government freight. Every department of the Government had the right, in the last war, to issue orders that had the effect of putting on the cars little red tags that said, "GOVERNMENT FREIGHT—PRIORITY". And, as Mr. McAdoo explained in his report, not only did every department of the Government have the right to issue those, but there was a keen competition in issuing them, not only between departments but within single departments. He gave an instance: They were going to build the Hog Island shipyard at Philadelphia and they knew that they would need a great deal of piling for that immense project. So they sent zealous young officers through the South where the piling is produced, with instructions to send piling to Philadelphia. And they performed their duties well; they sent piling to Philadelphia. Before anybody needed it or was ready to unload and use it, there were 5,000 carloads of piling standing around Philadelphia.

That was 5,000 cars out of action until somebody got ready to receive them and unload them, which in some cases was months. Not only 5,000 cars, but also precious track room in terminals taken up by those 5,000 cars. They were standing around in one another's way and in the way of everything else that was trying to move.

That is only one example of this practice, which not only went for Government purchases and shipments, but also for contractors who were engaged in the building of ports, camps, shipyards, and other Government projects. It went even for private shippers. It was the practice that if a shipper wanted 3 cars, perhaps he would order 5 from every railroad in town, and he might get 15 or he might not get any.

That sort of failure to recognize the essential nature of the railroad as a moving transportation machine was the great cause of the difficulty in 1917. That is the reason why comparing the railroads today statistically with the railroads of 1917 and 1918 is so misleading. It is true that we have in 1917 and 1918 something more than two and a quarter billion freight cars in this country; and we now have only about a million and three quarters. That is true. It is true also that we had then 70,000-odd locomotives, and now have less than 50,000. But there are some other facts; some of them the intangible facts that don't show in the statistics. Two which do show are that the freight car on the average is considerably larger now than it was then and very much better, and that today's locomotive on the average is more powerful and more efficient. But there are intangibles that can't be expressed statistically: the trains and the cars and the locomotives run on better tracks; they run through better yards, are protected by better signals, and are served by better shops; most important of all, they are handled by better methods than they were 20-odd years ago.

One great mistake caused the comparative failure in 1917. I say "comparative" because, in spite of all the talk, actually nine per cent more freight was handled on the railroads in the United States in 1917 than had ever been handled in one year up until that time. When the Government took over the railroads in 1918, at last there was somebody who could say which priority had priority over all the other priorities. And with that and other improvements, and with all the inherent tremendous increase in cost, the Government was able to move only three per cent more freight in 1918 than the privately owned and separately operated railroads had moved the year before. So 1917 was only a comparative failure, but at that, it was unnecessary. We, all of us, overlooked the essential nature of the railroad as a transportation machine.

That was a mistake that will not be repeated, because all of us—railroads, shippers, and the Government itself—have learned from that and similar experiences, and we have developed, not suddenly but over a period of years, a plan that definitely will eliminate the practice of loading freight into cars in advance of the ability of the receiver to take it and unload it.

FORMATION OF SHIPPERS' ADVISORY BOARDS

The year 1922 found the railroads in pretty bad shape, physically. That fall there was a very definite car shortage, the last general car shortage we have seen in these United States. Shippers out in the Northwest, around Minneapolis and St. Paul, were faced with the prospect of leaving the grain on the ground. They realized how much of the difficulty was due to shippers and how much to railroads, and how much to failure to work out a proper working arrangement between them. Voluntarily the shippers in the Northwest got together and formed the first shippers' advisory board. The movement was so successful in meeting a very critical situation in the Northwest that within two years it had spread over all the entire United States. Now there are 13 of these boards, organized on a regional basis. They are composed of traffic managers of industries, the men who actually have charge of moving about 85 or 90 per cent of all the freight that moves.

These boards are not crystal-gazers; they don't claim to be able to tell you what is going to happen next year or the year after next, but four times a year they do get together in each of their regions and from their individual knowledge of what their own individual businesses are going to do in the next three months they put down their estimates of car requirements. These are assembled, and they have been uncannily accurate over a period of 15 years. Also these regional boards make themselves responsible to co-operate with us in meeting any threatened congestion before it develops.

Last fall when the business of this country began to pick up rather sharply, and when, incidentally, there was a great deal of fear that the railroads would not be able to handle the situation, we created a port-control section of our car-service division. That port-control section receives daily reports from all the Atlantic and Gulf ports. It estimates the situation and watches for advance indications of threatened congestion. We don't intend to wait until the congestion develops.

How well this system is working is testified by the fact that few people know that it exists. At the peak of business in October 1939 the railroads handled 55 per cent more freight than in the preceding May. They handled it without the slightest difficulty. In the first six months of this year (1940), they have handled through the Atlantic and the Gulf ports more than 50 per cent increase in export freight as compared with last year. There is moving through the Port of New York now, and has been for nearly a month, more than 80 per cent as much export freight as was moved at the very peak of the World War movement in 1918, and nobody knows it is moving.

The test of this system is that it works. Last year we had to invoke our embargo remedy only once. The grain elevators in New Orleans were full and there were no ships to carry the grain away. Under old conditions we would have continued at the shippers' orders to carry grain to New Orleans and soon we would have had New Orleans blocked. But as we have worked things out in the past 15 to 18 years, we won't do business that way any more. With the full understanding and co-operation of the New Orleans people in charge, the railroads simply issued an embargo against New Orleans on grain. And until there was room made in the elevators, no more grain went to New Orleans. Simple? The plan of not loading freight that cannot be unloaded promptly at destination is so simple that some of our best "planning brains" don't think it is a plan at all.

Our system contemplates no supercontrol; it contemplates no disturbance of the ordinary way of doing things. It contemplates co-operation, and I might add that the proper departments of the Government have co-operated with us and we with them for 15 years on this, and that the Government itself, in its preparedness program or any other emergency which hereafter may come, is going to work right along with the railroads in keeping goods moving just as in the ordinary course of business. We know and they know and anyone who is close to the facts knows that the finest of all traffic control is not a superboard sitting at Washington. As smart as we human beings are and as full of statistics as we are, there is nobody yet who is smart enough to sit in Washington, or anywhere else short of Heaven, and plan out all the movements of all the freight in these 100,000 and more different cars that are shipped every day in the United States.

The best traffic control that ever has been devised is the control of the ordinary shipper about his own business, provided—and this is the one thing which we intend to provide—that nobody is allowed to load freight to an industry, port, or project of any sort, unless the receiver is ready to take it out of the cars promptly upon arrival and release the equipment for other service. Do that and it will insure that these essential channels of communication will be kept open and that we shall not have the difficulties in railroad transportation that we had in the time of the first World War.

Car supply is the thing that people talk most about, but car supply is relatively a minor factor in the whole operation of transportation. I already have said that we have fewer cars than we had in 1918, and yet in eight consecutive years since 1918 the railroads have handled more business than they did that year—as much, in some years, as seven and eight million cars more business, and done this with fewer cars and fewer engines. That largely was because during the 1920s the railroads spent about eight or nine billion dollars for additions and betterments. We largely rebuilt and modernized the railroad plant. The total size of the plant, as measured in mileage of line, is shrinking, but as measured in miles of track it has increased in size. Since the war period, the proportion of additional main tracks, yard tracks, and all other additional tracks has gone from a little more than one-half mile of auxiliary tracks for each mile of single main line, up to approximately two-thirds of a mile. The whole plant and operation have been made better. We built into the railroads the inherent and fundamental efficiency and capacity that are needed, and those are the things that take time, as you all know from your engineering experience. A realignment, a grade crossing, a new bridge, or anything of that sort can't be used until it is finished. Car supply, however, can be increased quickly and relatively easily. New cars are fed into the car supply as they come along. The improvements that take the most time and money already have been made to a large extent. Of course, there are still improvements that could be made, but so far as the capacity of the plant is concerned we have more fundamental capacity than we are likely ever to be called upon to use.

From people who see only half the picture, I have heard criticism of the railroads for having spent the money they did to improve the plant. The theory behind that view is that the railroad business in the 1920s was a dying or at least shrinking business and that the railroads were foolish to spend eight or nine billions of dollars to improve their plant.

RESULTS OF RAILROAD IMPROVEMENTS

The only answer to that again is the test of the results. In the year 1921 the operating expense of hauling a ton of freight 1,000 miles on the railroad averaged $10.78. In 1938, with both wages and taxes higher than they were in 1921 and with no material savings in the cost of materials and supplies, the operating cost of producing a 1,000-ton-mile of transportation on the railroads was down to around $6.50. That is the result, almost entirely, of the investment in better plant and the improved methods which that better plant has made possible. It is the gains which that improved plant and equipment have made possible which have kept the railroads ahead of the sheriff, in so far as they have stayed ahead of the sheriff, for the last ten years. Of course the sheriff has been right hot after us and he has caught up with nearly a third of us, although I must say that railroads have no monopoly on bankruptcy, particularly in depression times.

The one thing that gives all of us concern about the railroad-future is the fact that for the last ten years railroads, by and large, have not played their part as profit-makers in our so-called profit system—which more properly could be called our profit-and-loss system. And so we hear much talk about the railroad problem, and many remedies

prescribed for the railroad problem. But the problem is not a railroad problem. It is a public problem of transportation, and the difficulty about so many of the proposed remedies is that they overlook that fact.

A TYPICAL RAILROAD STORY

Perhaps I can illustrate the situation by telling the story of one small railroad, which in its essence is typical of the history of the railroads in the United States. Because it is a small railroad and because it is conspicuous and because its history can be telescoped into one lifetime instead of spread over a century, to me at least it is easier to see.

Once upon a time there was a man. Everything starts with a man, you know—a common two-legged man. This man was rather richly endowed with gifts; he had courage and creative imagination; he had capital and he had credit. It takes all of those to build a railroad. In front of him there was a wilderness; a wilderness of sand and palmetto scrub and alligators and Seminole Indians and not much else. This man took his talents and he built a railroad down through that wilderness. He took the world to the wilderness, and he took the products of the wilderness to the world. The wilderness became the east coast of Florida, one of the phenomena of our civilization. It blossomed and it bloomed, and, in fact, it boomed. The railroad had to add another track and a lot of capacity and equipment to take care of the needs of the traffic. Even today in these depressed years, during the peak season of the year, all that capacity and that extra track still is needed.

About the time the railroad got itself ready to meet the needs of a great business, the boom collapsed as booms will do. So the people decided to use their public tax resources to provide so-called "cheap transportation"—called cheap because the bulk of the cost is concealed in the public taxes. So down on the east side of that railroad, paralleling it from one end to the other, they built a canal and at the important points they built fine artificial and semi-artificial harbors. The canal was for the free use of anyone who was so fortunate as to be in a position to use it and there was much talk about the "savings to the shippers," but nothing was said about the cost to the taxpayers which was considerably more than the supposed saving to the shippers.

On the other side of the railroad they used public taxes to build a fine motorway, open not only to the ordinary automobilist on his ordinary affairs but equally open to those who do on the highways the same sort of business which the railroad does on tracks. The roadway was not offered as a free gift as the canal was. Some charge is made for the use of it and one can get into a great argument as to whether the charge is adequate or not.

Then over the top of that railroad they built an airway. Air is free, but radio beams and beacons and municipal airports are not free, except to those who use them—not for the taxpayers. The only place in which public tax resources could have been used to create a publicly financed and tax-supported form of transportation parallel to and in competition with that railroad that has not yet been tried is underneath. Nobody yet has dug a subway under it.

The railroad went into receivership. And why shouldn't it have gone into receivership? What form of business could be expected to meet the competition of its own Government and its own taxes under conditions of that sort and not go into receivership? The fact that railroads as a whole haven't gone into receivership is the astonishing thing. It is a testimony of the inherent strength and efficiency of the rail method of doing business.

More money has been spent out of public tax resources for so-called cheap transportation in the last 20 years than was spent on the railroads in 110 years. There is more public tax money in transportation facilities now than there is private investment. Most of the private investment—speaking now of fixed plant—is, of course, in the railroads.

More than 98 per cent of all the investment in railroads in the United States is private money. So much is heard about "land grants" that one might think land grants had built all the railroads that ever were built. Actually, less than 8 per cent of the mileage in the United States was built with the aid of Federal land grants. If you take the cumulative total of every conceivable form of public aid to railroad transportation that has ever been granted in 110 years, you will find that more than 98 per cent of the money that has gone into railroads has come out of the pockets of private investors—people like us—out of our savings and insurance policies and the like. That is not true of the fixed plant of other forms of transportation. We embark upon other projects of transportation, financed by what might be called involuntary investment of tax monies, with a blind indifference as to whether or not they are actually economically justified, because they don't have to pay their way.

"CHEAP WATER TRANSPORTATION"

Do you think that if we stopped for a moment to think of true economic justification we would build all these rivers we build over in the Mississippi Valley and elsewhere in the United States? Did you ever stop to think what it costs to build a river for navigation?

The New York Barge Canal, for example, was worth while once upon a time. It was a fine way of transportation, although even when it was built if they had listened to old John Stevens they would have built a railroad instead and everybody would have been better off; but they built a canal and it was useful to a degree. Of course there came the time when the railroad was built and the canal was not of much more use. It was never of any use in the winter time except to skate on. For a long time the railroad paralleling the canal was required by the State to pay on the freight it handled the same tolls that would have been paid had that freight been moved on the canal.

Then the time came when nobody would use the canal at all and pay for it. There is a curious superstition and popular belief that there is something in the Constitution of the United States that says that people who use inland waterways don't have to pay tolls. There is no such provision, however, either expressed or implied. There was a time when tolls were charged on most, if not all, improved inland waterways and the people who wanted to use them

were glad to pay the toll because that was the best form of transportation then available. But as was the case with the old Erie Canal, the time came when people no longer would use it unless they could use it free. So it was made free. And they wouldn't use it even then unless it was improved. So, beginning in 1903, the taxpayers undertook to improve the canal. They are still working on it. I don't know what that canal has cost; nobody knows because they didn't have original cost and depreciation accounting in the early days, but we do know what it has cost since 1903. Leaving out all the interest costs and maintenance costs and the like, the straight construction cost on that canal up until now is $357,000 per mile. The average annual maintenance cost exceeds $5,000 per mile per year. The freight-carrying capacity of the facility built at such expense and maintained and operated at such expense is only a small fraction of that of a good single-track railroad. And we call that "cheap water transportation"!

"Oh," you say, "That's a canal." And you ask, "What about the great natural inland waterways"? What natural inland waterways? There aren't any. There were once; Indians in canoes could go up and down the creeks and through the rivers and they didn't mind the sand bars. And the old shallow-draft stern-wheel steamboat could fight its way up and down the rivers and did a grand job that was worth while doing in its time. But the modern nine-foot inland-waterway barge has to have a built channel, and those channels cost money. The Ohio River, which is the best of the long-distance projects of that sort, has cost $142,000 a mile to build; and those miles are not measured on any straight-line distance, but are measured as the river winds. And it is costing about $4,000 per mile per year to maintain and to operate. To get that on a basis comparable with rail cost, you would have to add about 50 per cent to take care of the circuity, so we'll say $200,000 per mile is what it has cost to build. That compares with an average cost of about $62,000 per mile of railroad line, excluding buildings—just the track, bridges, and track structure. So a mile of the Ohio River cost three and a fraction times as much to build as the equivalent railroad mile. The average maintenance on a railroad in the United States is in the neighborhood of $1,700 or $1,800 per mile. The river costs nearly three times as much per mile to maintain. "Cheap water transportation!" And that's the best.

On the Missouri River up to Kansas City $198,000 per meandering Missouri mile was spent. And now $238,000 per mile and more is being spent upstream from Kansas City as far as Sioux City. The worst of these things is that they spread. Immediately a channel is built for one city, some other city says, "I must have a channel also to equalize the situation." The upper Mississippi channel has cost $228,000 per mile to build up to last year's report and it is only 81 per cent complete. I don't know what it will finally cost. The Illinois waterway has cost $170,000 and more a mile, and so it goes right through the list.

If people ever stopped to think what such projects mean in terms of actual transportation cost, I doubt if even the local businessmen's organizations would be for them.

What's the answer? Everybody knows that something must be done about the transportation problem. Most people talk about doing something to, for, or about the railroads; but nothing you are going to do to, for, or about the railroads alone is going to answer the problem.

The basic requirement for truly economical transportation in the United States is obvious although not easy to accomplish. That is to put all forms of transportation on the same footing. Put them all on the same level under the law. Let them all meet all of their own costs. Then naturally and necessarily each form of transportation will do the work it is inherently best fitted to do, and will do it at the lowest true cost. It would be foolish to talk about the railroads doing *all* the business of transportation in this country. They never did do it all. There were horses and wagons before there were railroads, and there have been horses and wagons ever since, and there are still going to be horses and wagons. Trucks can do some things better than railroads can. Boats can do some things better than railroads. Airplanes can do a few things better than railroads. For that matter, wheelbarrows can do lots of things better than any one of them.

In fact, I think the wheelbarrow is being sadly neglected in this modern time. I read an advertisement not long ago which appeared in some North Carolina newspapers. It was an advertisement by a group of trucking companies urging people to patronize trucking lines on the ground, among others, of providing great relief to unemployment problems because it took the services of ten times as many men to haul a ton of freight a mile on trucks as on the railroads. And that is about the correct proportion. But if we are going to look on our transportation from the point of view of relieving unemployment by increasing transportation costs, let's be consistent and go on back to the good old wheelbarrow. Then everybody would have a job. He wouldn't have much in his stomach while he was working and he wouldn't have much for clothes on his back and he wouldn't have much of a house to live in, but he'd have a job pushing a wheelbarrow.

That's almost the condition that prevailed in the world in the days before mass transportation by rail. So much of the labor of the human race went into the job of a little piddling transportation of a little shirttail full of this and that for short distances that there was but little capacity to produce. Even if there had been the great productive machinery now so common, it couldn't have been operated, because the raw materials could not have been assembled and the products couldn't have been distributed. The thing which has made possible the world as we know it is the fact that mass transportation in trains on tracks has released human energy to produce, and has made available to that human energy the resources of continents lost to man beforehand.

The thing to do, it seems to me, for a machine which has proved itself able to do that, and which is still doing it and doing it on a basis of true cost far lower than any other form of transportation, is to give that machine a fair and equal chance to do the thing it can do best. That will not be all the transportation, but it will be the movement of the great mass of the major commerce of this

continent. This should apply not only to the railroads, but to every form of transportation. We should set up such conditions of equality that each naturally would do its own job and not be digging around into the job of the others. Then, we'll have the best transportation we ever saw, and the cheapest. That is what everyone really wants.

The Case for Government Ownership

WILLIAM J. WILGUS

Former vice-president and chief engineer, New York Central Railroad

Before presenting a point of view which I fear may be shocking to some, I should like to mention a point made by my adversary. That was the reduction in costs per unit in transportation by rail. This has been and is marvelous, but we must not forget that the eight billions that were expended in order to bring that happy result have brought to the poor investors one-half of what they earned before the money was invested. And the cost to the transporter has gone up from $0.007 to $0.01 per ton-mile. So there is another side to this case which I hope you will bear in mind.

We are, of course, living in tragic times. As we look backward we realize that our forefathers 165 years ago were living in tragic times in facing the mother country in order that we might gain our independence. And some fourscore years later our fathers and grandfathers faced a similar situation when they had to put their shoulders to the wheel to hold together the Union which had been created as a result of the War of the Revolution. Then came the World War, in which we took our part in order to protect what we then believed in, the freedom of the seas. And now we have come down to these days, which to me and I think to you, are far more complex than those earlier times, because we have to cope with our internal economic difficulties as well as the protection of our fair land against attack from abroad in this world in flames.

Bearing those things in mind, we realize if we give thought to it that transportation is in a way the primary instrument in our social order to which we must look in solving these problems which, to the popular eye, are the outstanding ones. In some 55 years in the field of transportation, I passed through several periods of depression. The greater prior to this one, in the 1890s, brought to my attention the need for solving the rehabilitation of one of our great systems which had fallen into decay because of starved maintenance and improvement during that period. As to military needs in transportation, for nearly two years I had to do with the laying of foundations for the army transport system in France, and grew to realize that conditions are entirely different in times of war from those in times of peace in their drafts upon that organ we term transportation. Unless we have passed through the experience we cannot judge from the results in time of peace what we must cope with in time of war.

The facts that I shall lay before you will, in my judgment, lead you logically though reluctantly to the conclusion that the private ownership of our financially stricken disunited railroads is doomed. And with that admitted, you will, it seems to me, reach the further conclusion that upon their amalgamation into a harmonious whole under Federal auspices, their pressing needs for rehabilitation and improvement may be met and some form of co-ordination with their rivals in transportation brought about, all in the public interest.

We shrink, of course, from this further governmental invasion into the field of private enterprise, but in these days of peril we may no longer temporize with a situation fraught with danger. If private enterprise serving an urgent public need cannot finance its necessities, Federal intervention is the only recourse. Society, after all, depends for its very existence on travel and trade, and equally so on the movement of men and munitions for national defense. To the extent that the means of serving these purposes are faulty, to just that extent will our society suffer; aye, perhaps go under as have other civilizations in the distant past.

Transportation, then, is in all truth a social problem. As never before does it behoove us to take stock of our resources, so that without further loss of time we may be prepared against such fatal consequences as we are witnessing from day to day on the other side.

When we look backward over our national life span of 150 years, we see how man and animal power and the sail gave way to the steamboat, followed in succession by the steam locomotive, the electric motor and pipeline in certain instances, and finally the internal-combustion engine. Out of this Topsy-like growth has emerged a system of transportation in which chaos reigns, each of its five types at war with the others and within itself.

RAILROADS OF OUTSTANDING IMPORTANCE

Of these types—railroads, highways, waterways, pipelines, and airways—the first named, though sadly stricken in recent years through the diversion of competitive traffic to its rivals, still remains the backbone of our transportation machine and promises so to remain indefinitely so far as we can read the future. It is dependable in all kinds of weather—winter and summer, fall and spring. It reaches every nook and cranny in the land by continuous routes carrying freight in interchangeable equipment under uniform rules and regulations and joint through rates. It is adapted to speedy mass movements of persons and of property of widely differing weights and bulk. It is in brief a closely interwoven network of interdependent links united physically though disunited in a managerial and financial sense. None of its rivals can meet these conditions in full. In a national emergency it is vital for the swift dispatch of troops from all over the land to cantonments and thence to their objectives; and of the innumerable products of soil and forest and mine to mill and factory, and thence to storehouses, shipyards, ports, and scenes of conflict. Over its rails must move big-caliber naval guns on wheels for coastal defense and for distant bombardments of enemy centers; also guns and armor and machinery for battleships as well as modern engines of warfare such as mammoth tanks, all too heavy and too bulky for highway and air transport and too urgently required

on the minute for the winter interruptions, uncertainties, and long delays of internal movements by water.

RESULTS OF THE DEPRESSION

It is natural at this point to ask to what extent the railroads as a whole have suffered from the effects of the past ten-year depression. For an answer we have but to turn to the authoritative *Railway Age* of January 7, 1939, to learn that the results have been deplorable. Not only have items of equipment fallen off in great number, but what remain are to a large extent outmoded and over-age. Forty-five per cent of the cars are reported to be more than 20 years old and 70 per cent of the locomotives over 19 years old, both spelling inefficiency and costly upkeep. They call for replacement on a gigantic scale, in which shall be embodied advancements in efficiency, adaptation, comfort, and attractiveness in the public eye. Terminal and port facilities in many cases call for modernizing; bridges and masonry for repair and strengthening; embankments and cuts for widening, riprap protection, and drainage; level crossings for separations of grade; gradients and curves for reduction and straightening respectively. Main lines call for multiple tracking; sidings for lengthening; water and fuel stations for betterment and expansion; shop tools and work equipment for replacement and betterment. Centers of congestion call for bypasses; station buildings and right of way for freshening in the interest of good appearance. Rail, ties, and ballast call for renewal and betterment; signals and interlocking for extended use in the interest of safety and expedition; and other parts of the railroad machine as a whole, after so many years of neglect, likewise call for rehabilitation and improvement.

FINANCIAL NEEDS

It has been asserted by representatives of the Association of American Railroads that the picture is not as black as thus painted because the falling off in traffic during the past 10 years has resulted in a letup on wear and tear. This claim fails to give weight to the well-known deteriorative effect of rot and rust and frost and storm, and to obsolescence and inadequacy, all of which in the aggregate cause depreciation regardless of use. Generally it has been considered that two-thirds of the expense of maintenance is chargeable to the passage of time. If we compare the average annual outlays for maintenance prior and subsequent to 1929 we find that their decrease since that date, fairly assignable to the passage of time on a half-and-half instead of a two-thirds basis, amounts to more than a half-billion dollars per annum. A similar comparison of the sums annually devoted to improvements before and after 1929 shows a shortage of about the same amount. A combination of the two approximates $1,000,000,000 a year; a figure that coincides with that given in the issue of the *Railway Age* to which I have referred. That authority, quoting the words of the President's "committee of six" and the vice-president and general counsel of the Association of American Railroads, considers that that annual sum should be expended for several years in order that the railroads as a whole shall regain lost ground and meet the demands of the hour. For a period of 5 years, therefore, the railroads by and large should have poured into them some $5,000,000,000, a figure that is but slightly in excess of that given for improvements only by our fellow engineer, Ralph Budd, president of the Chicago, Burlington, and Quincy Railroad and now a member of the recently appointed Committee on National Defense.

I may perhaps be pardoned for adding a page from my own past experience in the rehabilitation and improvement of one of the principal systems of the country following the depression of the 1890s. Its main route traversed by crack trains gave no outward indication of grave defects that lurked beneath, nor of bad conditions on the side lines and branches and in terminals not visible to the principal officers and influential travelers who seldom if ever viewed them. Safety everywhere on the system was at stake; and the reasonable convenience and comfort of passengers whether they were carried in luxurious state on the main stem or in a humbler way in vastly greater numbers on the lesser routes. From my observations of today I feel that the same remarks are in order if our railroads in some degree are to win back their old prestige.

In a word, what is needed is an added investment in our railroads approximating $5,000,000,000 in order that they may meet their social obligations with satisfaction to their patrons of high and low degree and, above all else, faultlessly back the Army and Navy in our hour of trial.

VANISHED CREDIT

How is this enormous sum to be raised? Certainly not from private sources unbacked by the Government. The railroads' share of the total national income since 1919 has been steadily downward in good times and bad. Their average revenue per ton-mile since 1916, in an effort to make up for their striking losses in passenger revenue, has been maintained at a far higher level than the price level of the commodities they carry, thereby driving their shippers into the arms of their rivals. Their net operating income since 1916 has dropped something like a half, though some $8,000,000,000 have been poured into the enterprise. Two-thirds of their mileage is in the courts or on the ragged edge of insolvency. Their bonds in large part have been removed by the State of New York from its list of permissible savings-bank and trust-fund investments. Their stocks—that is, their venture capital—are with rare exceptions unsaleable, although essential in private enterprise as a cushion for the protection of the funded debt. Their consolidation into a limited number of systems, with the accompanying scaling down of their securities to modest limits, has no promise of accomplishment in the reasonably near future. Briefly, the credit of the railroads as a whole has vanished. Their only recourse is Government aid which at present is extended to them on a comparatively small scale, and in reality is a backdoor entrance to complete control without responsibility for the outcome.

GLOOMY PROSPECTS

It will be said, no doubt, that the present upsurge of war traffic points to the coming of better days. But

surely this cannot be viewed as a permanent or for that matter a temporary solution. The aftermath of war, as proved by history, will be quite the other way. Even as it is the railroads in large part are still in the depths of despond. During the first quarter of this year more than one-half of the RFC-selected Class I railroads in the New England and eastern regions failed to earn their fixed charges, one-third in the southern region, 90 per cent in the northwestern region, three-quarters in the central western region, and nearly a half in the southwestern region. Only in the Pocahontas region were fixed charges earned in full by all three roads. In the aggregate, 44 out of the 81 railroads fell by the wayside and of these 11 did not even earn their operating expenses and taxes! On top of this it is to be expected that taxes and costs of materials as a result of our measures for defense will go up, while freight rates will remain stationary or continue downward. In light of the past and present, and of what is ahead of us in a world of turmoil, we must not rest our fate as a nation on wishful thinking. The money required to put the railroads on their feet is as much needed right now as are the billions of new money at present being appropriated for our other means of national defense. We cannot for our nation's safety afford to rest its fate on a hoped-for railroad comeback not now in sight.

A FEDERAL RAILWAY AUTHORITY

By many this additional call for funds on such a scale will have an ominous sound. But rightly handled it is not to be feared. Taken over by a Federal Railway Authority in return for its low-interest-rate securities, the railroads as a whole should not cost more than 50 per cent in excess of their market value of some $10,000,000,000 as of a year ago, or say $15,000,000,000 in all. The actual annual net operating income during the past 10 years has averaged enough to support an investment of $20,000,000,000 at the Government's present low rate of interest. The difference, $5,000,000,000, raised through the sale of the Authority's securities, would pay for the needed rehabilitation and improvements. In addition the money thus released from the country's frozen resources would relieve our WPA rolls and inject new life into the arteries and veins of many of our moribund industries.

Time now being of the essence, the railroads under this plan would be taken over at the stroke of the bell, as they were at the beginning of 1918, on the basis of a fair annual rental as was done at that time, pending the determination of their fair value in courts to be set up for the purpose. With this would go a form of co-operative management, free from politics, in which the five interests involved—executives, labor, shippers, investors, and the public-at-large—would take their part. In this connection I venture to direct your attention for details to an article from my pen in the October 1939 issue of *Civil Engineering*, where I endeavored to show that this could be handled without politics.

There are several reasons why no time should be lost in bringing this about. Our equipment plants and steel mills will have no room for railroad needs if they are to become loaded to the limit of their capacity with orders for munitions at home and abroad. Lines in whole or part incapable of earning a commercial return, like the Ontario and Western, Rutland, Old Colony, Long Island, Norfolk and Southern, Chicago and Northwestern, Omaha, Alton, and Minneapolis and St. Louis railroads, may be abandoned in whole or part if not rescued for national defense. After all a main line or branch essential in an emergency for the transport of troops and supplies, or gun-mounts or tanks, should not be expected necessarily to earn its way, any more than the battleship or army is expected to yield a money return. Again, a speedy survey of the railroad situation in qualified hands should determine not only what rehabilitation and improvements should be undertaken in their proper order, and the estimated cost of so doing, and what lines should be retained from the angle of defense regardless of their earning power, but also what lines with propriety really should be abandoned so as to obviate expenditures upon them, as for instance for the elimination of grade crossings, which would be thrown away.

CO-ORDINATION A NECESSITY

With the making of the railroad survey of which I have made mention should go similar action in the other types of transportation, not with the idea that they should be taken over by the Government, but to determine their scope and nature, and the extent to which public regulation should be instituted in the interest of all; also to inaugurate an organization whereby their activities and those of the nation's railroad system may be co-ordinated somewhat as I have indicated in the *Civil Engineering* article to which I have previously referred.

I have endeavored to express my deep conviction that transportation in the United States is a social problem of the first magnitude that must be wisely solved, and that, too, without further loss of time, if the country is to be put in readiness for defense. Others may have a different solution than mine. If so, I pray that they may speak up convincingly. Whatever it may be I venture the belief that it should be founded on the principle that "united we stand; divided we fall". A disunited system of railways will no more succeed in its aim to protect the interests of the nation, than did our confederation of states politically before we became the United States. The Association of American Railroads, as now constituted, is without power to enforce its decrees. Its members very naturally have first to serve their individual interests not those of the system as a whole. No temporizing will cure this defect. Co-operative management under Federal auspices will, as I see it, accomplish that end, and in co-ordination with the other means of transportation cement all of them together for the nation's good.

To repeat then, if the solution I have proposed is deemed to be faulty, what is the alternative that will loosen the country's funds so that they will flow instanter into the field of transportation?

MISCONCEPTION OF WAR NEEDS

Colonel Henry has discussed the quickened movement of trains and cars in recent years. But this will not make up

in war time for the railroads' lessened volume of equipment. Needs for cars and locomotives in areas of conflict—theaters of operation, as they are called—are likely to be very heavy. For these the home railways will have to yield of their stock on hand. In France during the World War we had on demand upwards of 5,000 locomotives and 100,000 cars. Allies, too, on this hemisphere or elsewhere will look to us for aid in this particular. The exigencies of war cause upsets in regular schedules with resultant lessening of the efficiency usual in peace time. Solid trains of empty cars, without awaiting loads, often must be sent long distances for urgently needed materials. I say in that connection, suppose our Panama Canal were put out of commission. Railroads would have to come to the rescue. Interruptions or curtailments in our intercoastal or other coastwise water traffic would throw a greatly increased burden on our rails. Loaded cars will be held immobile at ports when shipping may be held up by ice or unanticipated war conditions. Losses in the field will reduce the available stock of cars and locomotives. Trained personnel must be drawn upon for the operation of military railroads, leaving untrained men to take their places with an unavoidable loss of efficiency in train and car movements. Friction resulting from enforced diversions of traffic from one road to another, such as occurred in the World War, will have baneful consequences. I speak of these from personal knowledge. No greater mistake can be made than to close the eye to these conditions, to deny experience, and to invite a breakdown of our transportation machine at some critical moment in our affairs.

A CALL TO ACTION

After all, it is to our means of intercourse that we must look for the preservation of our civilization, for the continuance of the institutions we hold dear. Doubly is this true in these days of peril when we must be prepared, and that quickly, to back our Army and Navy to the limit. Neglect in this, especially in a land so broad as ours, may well lose to us their fight in our defense, as have the shortages in tanks and airplanes brought defeat to the Allies across the sea. Financially and physically must we speedily put in perfect order our railroads, the backbone of our transportation, and unite them for one common purpose—the welfare and safety of the people of the United States.

In calling for that action, it seems to me organization and leadership must come first. In round figures we have 80-odd independent Class I railroad systems. In other words, we have 80-odd generals, with no commander-in-chief who can impose his will upon them as Foch did upon the Allied armies during the World War. Then, what is even worse, we now have supervising them six independent agencies with a promise of a seventh. There are the Quartermaster Corps and the Corps of Engineers of the United States Army. Also, we have the Interstate Commerce Commission which, as stated in the provisions of law which were quoted in its report to Congress on November 1, 1939, has the right to exercise managerial powers. Then we have the Association of American Railroads filling a very fine purpose without executive force, without the power to enforce its decrees. Then we have the so-called Owen D. Young committee which is for the purpose of investigating over a period of unknown time, perhaps a year or two, and then bringing in some kind of a report, as to which there may or may not be unanimity of approval. Then we have the Council for National Defense with its branch devoted to railroads under Mr. Budd. Just how he can function in harmony with the American Association of Railroads and with these 80-odd different railroads so far as I know is unknown. And then we have the possible transportation board to be organized under the provisions of the Wheeler-Lee bill that so far has not had Congressional action. Should that be passed, you have seven of these different agencies, all milling around without any single leadership to bring them together and have the railroads work together as a unit.

You may say, "Why is it necessary for them to work together as a unit?" We have the weak and the strong. The weak are just as essential to the functioning of this network as a weak link is to the strength of a chain. The strength of a chain is measured by its weakest link; so is that of our network. We have such railroads as the Chicago and Northwestern, Ontario and Western, Rutland, Long Island, Alton, Soo, Denver and Rio Grande, and Norfolk and Southern tottering. Twenty-five out of 133 Class I railroads failed to earn their expenses and taxes in the first six months of this year; 48 out of 81 failed to earn their fixed charges during the first five months. Their failure means the entire network is in danger. As I see it, that lack of leadership, that lack of solidarity, that very lack of the principle that has made our 48 states a Union is what now demands a cure.

(*Editor's Note:* Following Colonel Wilgus' address, the meeting was opened to discussion, and Colonel Henry was offered the opportunity of presenting a "rebuttal." The substance of his additional remarks follows.)

Further Defense of the Railroads

ROBERT S. HENRY

Colonel Wilgus' statement that the average charge to shippers, as measured by the average revenue for hauling a ton of freight a mile on the railroads, has gone up from $0.007 to $0.01, is true if you take a sufficient length of time and ignore the intermediate period. The seven-mill rate prevailed before the first World War. A great many things have changed since that time. For example, back when seven mills was the average charge per ton per mile for handling freight, the railroads were paying to government for taxes approximately two cents out of each dollar of revenue taken in. Last year the railroads paid in taxes just under ten cents out of each dollar taken in. In the days when railroads were handling freight at seven mills per ton per mile, the wages of engineers, conductors, and all other labor were less than half of what they are now. My recollection is that the average railroad wage in that

period was 20-odd cents an hour. Today it is 75 cents an hour.

Now in between that time and today was the period of the World War. At the conclusion of the World War period the average revenue for hauling a ton of freight a mile in the United States was $0.01275. Last year it was $0.00985. That comparison gives a measure of the improvement and of the decrease in charge which has kept pace with decrease in cost in those years.

For his description of the rather parlous state of the railroads Colonel Wilgus relied rather heavily upon the statements of *Railway Age* of January 1939. In May 1939, President Roosevelt, through Secretary Morgenthau, asked two very eminent railroad men, Mr. Willard of the Baltimore and Ohio and the late Mr. Carl Gray of the Union Pacific, to give him a report as to what the situation would be on the railroads in an emergency. They made a report in May 1939, which at that time was confidential, in which they said that with the condition of the railroad equipment as it was then the roads could handle an increase of 25 per cent above the tonnage they were then handling, and that by putting the equipment into full repair, the roads could handle 45 per cent more.

At the beginning of September 1939 war broke out in Europe. On the same day appeared the *Railway Age*, which is an authority and a very ably edited paper, but is not, as is sometimes thought, an organ of the railroad industry; it is a trade paper concerned with both the railroad industry and the railroad-supply industry. The *Railway Age* printed elaborate statistical calculations to prove that the railroads would absolutely break down under the load in the fall of 1939.

That was September 1, 1939. Then what happened? In October 1939 railroads in the United States handled not 45 but 55 per cent more freight than they had been handling in May. They handled it without any car shortage, congestion, delay, or difficulty. And the repair program to which I referred had not been put fully into effect.

Now what is the condition today? The first of June 1940, there were 36,000 or 37,000 more serviceable freight cars in operation in the United States than there were on the first day of October 1939. And remember that in 1939 the railroads handled whatever was offered, which was a good deal more than anybody had anticipated, and handled it without difficulty.

So far as the war load is concerned, the railroads do not anticipate any tremendous increase. Of course the operating difficulties which Colonel Wilgus mentioned no doubt will develop, particularly if war should come to the American continent. But as for the preparedness program and the tonnage to be anticipated at any time in the near future, there is no reason to expect any such increase as is commonly referred to. The war load in the United States in 1918, as nearly as can be determined from the studies we have been able to make, was only a 12 per cent increase above the previously prevailing level. Last year the railroads picked up a 55 per cent increase in four or five months without serious difficulty.

That is not to say that the railroads are just as we should like to have them. Very few of us connected with industries find things as nice as we should like to have them; very few of us have the plant that we should like to have. Of course further improvements will be made in the railroads. There always have been. They are made more rapidly in good times and more slowly in poor times, but the process does not stop. So far as this idea that the railroads are staggering in a decrepit and broken-down condition is concerned, let me cite you a few facts.

The railroads spend less money per mile on track maintenance than they did before 1929, a great deal less. And never again will they spend as much per mile for maintenance as was spent before 1929, because it isn't necessary. Twenty years ago less than half the cross ties in the railroads were creosoted and treated timbers. Now five-sixths or more are treated ties which last three or three and a half times as long as an untreated tie. Twenty years ago when a rail became worn on the ends, it was taken up and relaid in a sideline somewhere. Now when a rail wears on the ends, crews build up that worn end right in place in the track with a welding process and when they get through the rail is practically as good as new, and at a cost much lower than for the earlier practices. Improvements could be made, of course, and they will be made wherever they are economically necessary and economically justified.

But consider the record of what the railroads have done in the last few years in spite of all their difficulties. Take the one element of safety. The accident rate on railroads is now one-fifth of what it was 20 years ago. Your chance of getting hurt on railroads, whether you work on the railroad or ride on it, is one-fifth what it was 20 years ago. The chance of your freight being damaged on a railroad is one-sixth of what it was 20 years ago. And, as Colonel Wilgus has said, we are moving the trains faster. We are getting more than twice as much use out of a freight train as we did 20 years ago. That isn't the record of a "decrepit machine"; that isn't the record of a machine that is creaking at the joints and falling to pieces. That isn't the record of railroads that are stuck together with chewing gum and chicken wire.

So we in the railroad business see no necessity for any tremendous sudden programs of rehabilitation of the plant. If a necessity seriously existed, of course we would have to give serious consideration to it, but the remedy proposed of Government ownership and operation of railroads reminds me of an experience. At an anthropological museum out on the Pacific Coast there is a collection of ancient Peruvian skulls. Some of the skulls have little holes in them which the curator explains as having been caused by the headache remedy which the ancient Peruvians used. When a man had a headache the witch doctors decided that his trouble was a devil inside his skull. So they took their bone knives and scraped a hole in his skull to let the devil out. And they cured the headache.

We have a democracy in the United States and I hope we shall always have it. It is a thing that is worth fighting for. And what is the essence of it? That we are free men; that nobody has complete control over us. The Government has political control, true; the church has spiritual control, maybe; the diverse and diffused economic powers have some economic control. The separation of pow-

ers as between church, state, and economic order is the great achievement of the last 150 years. And the greatest single step to be taken in this country toward what we now call totalitarian government—which in the days of George Washington and the men who wrote the Constitution was called absolute monarchy—would be to concentrate again in one place and under one control both economic and political power over the lives of men. And the greatest single step toward that, as I see it, would be to turn the railroads over to our Government to operate.

That might cure some of the troubles. The Peruvian's headache disappeared—and so did the Peruvian.

Of course I realize that I am not answering what Colonel Wilgus said. He said that he believes—most conscientiously and patriotically, I am sure—that the salvation of our nation depends upon achieving certain effects with our railroads. We of the railroads believe that those effects can be achieved better through the present way of doing things. It is true that there are about 80 separate systems in the country. It is true that there is no absolute control over them except that which the Interstate Commerce Commission could exercise if it thought necessary, but which it has not yet seen fit to apply. But I am not sure that this diversity is entirely a weakness. I am not so sure of the omniscience and the all-pervading abilities of the gentlemen in Washington. I am not so sure but what there is an advantage in having railroad headquarters scattered about all over the United States. I am not so sure but what the competitive spur has produced more than it has cost. That is a question for argument and speculation.

One other thing—there are certain railroads that are necessary in time of defense which are not necessary or even desirable for commercial purposes. By way of comment on that point I shall outline an interesting but little-known fact. In 1869 the Southern Pacific Railroad built a line from Ogden, Utah, around the north end of the Great Salt Lake. Later they built another line over about 30 miles of trestle and bridge across Great Salt Lake. Shortly thereafter, the Western Pacific built a line from Salt Lake City around the southern end of Great Salt Lake. All these ran into the San Francisco Bay area. The old line around the north end of the lake having ceased to be of any real commercial use, about six years ago the Southern Pacific Railroad asked authority from the Interstate Commerce Commission to abandon it. The War Department intervened, among other objectors, pointing out that in case of an emergency in the Pacific the San Francisco Bay area would be vital and that all possible tracks might be needed. Subsequently the Interstate Commerce Commission, whether for that reason or for others, refused to allow the abandonment of the line and it is now being maintained and operated by the Southern Pacific Railroad, as an element in the national defense.

There might be other such situations, and it may be that special adjustments should be made to take care of such things. But that's a totally different thing from handing over the operation of these railroads to the Government of the United States. It is a great Government in its field; but its field is government and not running railroads.

Magnetic Storms

DURING the great magnetic storm of April 1938 energy was expended at the rate of two billion kilowatts for a two-hour interval. Couched in more comprehensible terms, this is 100 times the capacity of all the hydroelectric developments in the United States and 4 times the estimated potential developments of the entire world. The magnetic storm of March 1939, which produced so much disturbance on power and communication lines, seems to have been greater than the 1938 storm; possibly it is the greatest ever recorded.

A number of generalizations may be drawn from our knowledge of magnetic storms. In the first place, each storm is world-wide. Of course, there are regions where the effects of such storms are more pronounced than at others. In equatorial regions the effects are least violent, while at a distance from 20 to 30 degrees from the geomagnetic poles—the auroral zone—they attain their maximum intensity. One outstanding feature of great magnetic storms is that this auroral zone shifts to lower latitudes.

Mathematical analysis has shown that field changes during magnetic storms are due principally to causes above the earth's surface, presumably electric currents, and that these external effects are accompanied by effects due to the induction of currents within the earth by the primary external fields. The field changes may be divided into two classes—those which are symmetric about the earth's magnetic axis and those which are nonsymmetric. The latter are associated with electric currents flowing with maximum intensity along the auroral zone. Field changes arising from these currents are responsible for the effects on communication and power lines. The strength of the auroral-zone currents may exceed 1,000,000 amperes, and changes exceeding 100,000 amperes in one minute have been observed. Changes of from 10,000 to 15,000 amperes per second would be sufficient to produce electromotive forces of the magnitude required for effects on power lines (about 10 volts per mile).

The cause of the primary electric currents in the outer atmosphere or about the earth remains a matter of speculation. Regardless of the causes of magnetic storms, however, there is nothing scientists or engineers can do to control them. Their effects on power and communication lines can be reduced to inconsequential importance by suitable installations, but the cost of these installations involves economic considerations. Judging the future by the past, great magnetic storms may be expected at the rate of one a decade. Records go further than this: They show that the frequency of magnetic storms of all intensities follows the 11-year sunspot cycle, lagging behind it by about two years. The evidence does not recommend that drastic steps be taken to minimize the effects of magnetic storms on power and communication lines, for it assures that such effects as occurred in March 1939 will rarely be repeated.

Abstracted from an article of the same title, by A. G. McNish, published in the Edison Electric Institute *Bulletin*, July 1940, pages 361–4, 370.

Institute Activities

A Message From the President

To Members of the Institute:

THE AIEE has entered upon its 57th year. As usual at this stage of the Institute year a new president is in the chair. He is very happy to be your president and proud of the fact that he is an engineer. In order that you may know how interesting he has found being an electrical engineer and a member of the Institute, he is going to risk criticism for lack of good taste and tell you some of his engineering experiences—not that he would boast of any of them, but rather that he might neutralize some of the pessimism brought about by the discouraging actions of humans. He trusts that his words may cause those members of the profession who have practiced for a time to recall their own happy experiences, and may indicate to the younger members possibilities for happiness which cannot be destroyed even by tyrants lusting for power. He started being an engineer before the days of vacuum tubes and electronics, yea, even before the days of "wireless," by climbing distribution-line poles, fixing primary-battery-powered doorbells, and displacing coal-oil lamps by wiring old houses.

Each phase of his engineering life—lineman, stoker, power station operator, student, testman, designer, teacher, consulting engineer, and what not—has contributed generously to an abundant life and brought many opportunities clamoring at his door. Would that he could have recognized more of those opportunities and let them in!

As long as memory lives he will recall the thrills that came when he conquered a stubborn pair of climbers and learned how to make them take him safely up a pole and down again without accumulating too many splinters; when he learned the little twist of the wrist that spread the coal properly and placed it in just the right place in the firebox; when he learned how to test "on the fly" by a trained sense of touch the condition of moving engine parts and squirt a bit of oil into just the right places to keep the machinery operating smoothly; when he learned to open the throttles properly to bring sleeping engines and their dynamos into activity, and by closing a few switches to send the electric current out over the circuits into homes and places of business; when he conquered a puzzling calculus problem or became aware of the meaning of a sentence in a science textbook; when he was the first to apply power to a newly built transformer or other machine and compare its measured performance with design calculations; when he saw a testman test one of his own designs and find that measured test values showed the design to be correct to specifications; when he saw some fortunate exposition he made open to students a glimpse of how to solve engineering problems and what it means to be an engineer.

He had the capacity to gather only a few fragments of those many opportunities presented to him, but those fragments are burnished bright by memories of friendly assistance on the part of his associates too numerous for him ever to repay. To cap the climax you have made him president. He is experiencing "the thrill of a lifetime," and why not? If he could live his years over again he would choose to be an electrical engineer and a member of the Institute, the official professional society for electrical engineers. As a working member of AIEE he has had a deal of satisfaction in doing his bit for our great organization. As your president he is having the pleasure of taking over the throttle of an efficient, smoothly operating organization. During the past year President Farmer, the board of directors, National Secretary Henline, National Treasurer Slichter, and all the staff have done a good job and turned over to the present administration an Institute in excellent condition with all business completed to date. Indeed, in every way our Institute is on the right track and making good speed ahead.

Your president has no illusion that this sudden honor granted him by the grace of God, favorable chronology, geographic influences, and the activity of friendly professional colleagues in the Institute has brought with it any endowment of new ability to serve properly as your chief officer for the current year. He pledges you, however, that he will do the best he can. We are in for a good year. The members who have been asked to serve on committees and in other capacities have responded with enthusiasm. Papers of interest are being written. Our budget is balanced, and, although less than we would choose, is after all no mean sum which serves quite well the financing of our planned activities.

To all members who have made these things possible your president extends thanks and congratulations. He can wish them no greater joy than to hope that all

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Royal W. Sorensen, President AIEE 1940–41

who have been engineers for some time have found a measure of satisfaction in proportion to their years in the profession equal to that which he has experienced. To those new in the profession he can hold up no reward greater than the wish that they will have an interest in the profession and a joy equal to that which has been his. Moreover, he is certain that the future for engineers holds even more promise than the past. Men such as those who have made the engineering profession will not let America die or let the ideals of her people be trampled in the dust.

To attain such hopes every one of us must work for our profession and through it for our country and its ideals as never before. Engineers need not be told what to do, because professional men have the vision that enables them to discover what should be done as well as the ability to do it.

Our job is to engineer, and that we must not neglect. Through the officers of our Branches, Sections, and Districts, we must continue the work of the Institute. In the present world crisis, engineers must not be satisfied with making a product that is good, but must become active in adapting that product to the special needs of the day —national defense; hence the resolutions pertaining to that subject passed by your board of directors and published in the August issue of ELECTRICAL ENGINEERING. Engineers must become more active in having a voice in determining how the world shall use science and engineering. To do this they must enlarge the circle of their activities and, through channels provided by political and other nontechnical organizations, make their proper contributions to human progress. Engineers must insist on the right to equal partnership with other people in all the affairs of men, but in so doing they must not think engineering knowledge alone gives claim to speak on other matters.

As you think over these things keep ever in mind the fact that the Institute is a "co-operative-voluntary organization" which has value directly in proportion to the integrated activity of its members. Thus it becomes not only the privilege of each member but also his duty to take some part in its program. Nothing less will make the Institute all that we would like to have it. Further, only by such active participation can you as individual members realize the full potential value of your membership, for "Whatsoever a man soweth, that shall he also reap."

Royal W. Sorensen

Middle Eastern District Meeting To Be Held in Cincinnati October 9–11

THE only Institute District meeting to be held during the remainder of 1940 is the Middle Eastern District's meeting, scheduled for October 9–11 in Cincinnati, Ohio. Taking advantage of this fact, the committee responsible for that meeting has extended a special invitation to all Institute members and their families. In support of this invitation, the committee has arranged a program of unusual interest, and has emphasized the fact that Cincinnati is centrally located and convenient of access from all directions. Headquarters will be in the heart of the city, at the Netherland Plaza Hotel where air-conditioned meeting rooms will be available for the technical sessions.

The "Queen City" affords many unusual opportunities for recreation and sightseeing, full advantage of which has been taken in the arrangement of the entertainment and inspection-trips programs. A diversified technical program of topics of timely significance has been provided. The annual business meetings of the District executive committee and of the District committee on student activities will be held. The Student Branch convention will provide students with an attractive program especially devoted to their interests.

ENTERTAINMENT

A bridge luncheon for women guests is scheduled to be held in the Red Alcove of the headquarters hotel at noon on Wednesday, October 9. That afternoon is reserved for shopping. At 6:30 in the evening there is to be a smoker and buffet dinner in the ballroom of the Hotel Metropole. Evening entertainment for women will be provided at a large radio studio where they may witness the presentation of a national feature program.

Thursday morning, October 10, women guests may visit the new laboratories of the Kroger Food Foundation. In the afternoon they may attend a musicale and tea at the old colonial home of the late Charles Phelps Taft, where famous collections of paintings, French enamels, Italian majolica, and Chinese porcelain will be on display.

Thursday noon a men's luncheon will be held on the Pavilion Caprice Terrace at the Netherland Plaza. The gathering will be addressed by C. T. Sinclair, AIEE vice-president for the Middle Eastern District. In the afternoon an inspection trip is scheduled to the Newport Rolling Mills and Andrews Steel Company, Newport, Ky. Those not interested in this trip may substitute the sightseeing tour around Cincinnati.

In the evening in Pavilion Caprice an informal dinner will be held over which Professor A. M. Wilson of the University of Cincinnati will preside as toastmaster. A feature address is planned.

For Friday, October 11, a special inspection trip through the Ivorydale Plant of the Procter and Gamble Company has been arranged for women. In the afternoon a sightseeing trip for family groups will visit points of interest in the city and environs, including Cincinnati's famous parks, university, art academy, Rookwood pottery, etc. There also will be a "communications tour" on Friday afternoon for those who wish to visit the studios and transmitter of Station WLW and the Crosley television station, as well as a trip to the Columbia station of the Cincinnati Gas and Electric Company.

Cincinnati has many fine golf clubs where devotees of the game will find opportunities to demonstrate their prowess. No tournament has been scheduled, but the entertainment committee will arrange for play upon request.

The University of Cincinnati will play a night game of football with Centre College on Saturday, October 12. Other major games in nearby cities will be readily accessible.

Hotel Rates

	Room With Bath	
	Single	Double
Netherland Plaza, 5th and Race Sts.	$3.00–10.00	$5.50–12.00
Gibson, 5th and Walnut Sts.	2.50– 6.00	4.00– 8.00
Sinton, 4th and Vine Sts.	3.00– 6.00	4.50– 9.00
Metropole, Walnut Street	2.25– 3.00	3.50– 6.00
Alms, McMillan and Victory Parkway	2.50– 4.00	4.00– 6.00

STUDENT BRANCH CONVENTION

The sessions, entertainment, and inspection trips of the Student Branch convention are open to all Enrolled Students. They are cordially invited to be present at the smoker and buffet dinner on Wednesday evening. A special price of 75 cents prevails for Students.

Of particular interest is the student-counselor luncheon to be held at noon Thursday, October 10, in the Netherland Plaza Hotel. The price of this luncheon is $1.00 to counselors, 75 cents to students. The inspection trip to the Newport, Ky., plant of the Andrews Steel Company probably will be a feature of the student program. Detailed information for student members is scheduled to reach all Branches in the District about three weeks prior to the convention.

REGISTRATION AND HOTELS

Members who plan to attend the meeting should register in advance. A minimum registration fee of $2.00 will be charged all nonmembers, except Enrolled Students and the immediate families of members.

Room reservations should be made by writing directly to the hotel preferred. Room rates for the headquarters hotel, Netherland Plaza, as well as several of the other hotels, are given in the accompanying table.

COMMITTEES

District meeting: C. T. Sinclair, vice-president, Middle Eastern District; W. J. Lyman, secretary, Middle Eastern District; A. C. Burroway, L. R. Culver, R. S. Fields, R. W. Prince, V. G. Rettig, M. S. Schneider.

General: R. S. Fields, *chairman;* C. F. Lee, chairman, Cincinnati Section; L. L. Bosch, A. C. Burroway, L. R. Culver, C. Fortenbaugh, J. A. Noertker, Mrs. J. A. Noertker, V. G. Rettig, M. S. Schneider.

Tentative Program—Middle Eastern District Meeting

Wednesday, October 9

9:30 a.m. General Meeting

E. S. Fields, presiding

Welcome. James Garfield Stewart, mayor of Cincinnati

Acceptance. C. T. Sinclair, vice-president, Middle Eastern District

10:00 a.m. General Session

DP.* Sun-Spot Disturbance of Terrestrial Magnetism. **W. F. Davidson,** Consolidated Edison Company of New York, Inc.

DP.* Long-Term Weather Forecasting. **C. G. Rossby,** Weather Bureau

DP.* Fundamental Considerations of the Mill Creek Valley Barrier Dam Flood-Pump Project. **W. A. Farris, H. A. Seaman,** and **R. C. Vogt,** United States Engineers

40-161. A Push-Button Tuned 50 Kw Broadcast Transmitter. **R. J. Rockwell** and **H. Lepple,** WLW, Crosley Radio Corporation

2:00 p.m. Power Transmission and Distribution

40-143. Increased Capacity and Interconnections of the Columbia Gas and Electric Corporation. **C. W. DeForest,** Columbia Engineering Corporation

DP.* High-Capacity Air-Blast Circuit Breakers. **H. E. Strang,** General Electric Company

40-137. The Effect of Overexciting Transformers on System-Voltage Wave Shapes and Power Factor. **J. W. Butler** and **E. B. Pope,** General Electric Company

40-144. Some Insulator Designs Require Special Features to Insure Radio Quietness. **C. J. Miller, Jr.,** Ohio Brass Company

40-160-ACO.† Developments in Carbon-Dioxide Fire Extinguishing Systems and Application to Electrical Machinery and Equipment. **Eric Geertz,** Cardox Corporation

2:00 p.m. Aviation Instruments and Control

DP.* Automatic Control of Aircraft. **C. D. Barbulesco,** Antioch College

DP.* Application of Electrical Power in Aircraft. **T. B. Holliday,** United States Army Air Corps

DP.* Electrically Operated Remote Indicating Instruments. **G. F. Tate,** United States Army Air Corps

40-157. An Electrical Engine Indicator for Measuring Static and Dynamic Pressures. **E. J. Martin, C. E. Grinstead,** and **R. N. Frawley,** General Motors Corporation

DP.* Aircraft Lighting. **A. D. Dickersen,** United States Army Air Corps

Photo-offset copies of authors' manuscripts, except addresses, may be obtained as soon as available in advance of the meeting by writing to the AIEE order department, 33 West 39th Street, New York, N. Y. Only numbered papers will be available in advance-copy form. If ordered by mail, price 10 cents per copy; if purchased at Institute headquarters or at the convention, 5 cents per copy. Mail orders (particularly from out-of-town members) are advisable, as an adequate supply of each paper at the meeting cannot be assured. Coupon books in $1 and $5 denominations are available for those who wish to avoid remittance by check or otherwise. Most of the papers ultimately will be published in ELECTRICAL ENGINEERING or the TRANSACTIONS.

Thursday, October 10

9:00 a.m. Electrical Machinery

40-138. The "Black-Band" Method of Commutation Observation. **T. W. Schroeder** and **J. C. Aydelott,** General Electric Company

40-139-ACO.† Large 3,600-RPM Induction Motors. **P. C. Smith,** Westinghouse Electric and Manufacturing Company

40-155-ACO.† A New Development in Wound-Core Distribution Transformers. **J. O. Fenwick** and **D. E. Wiegand,** Line Material Company

40-158. A New Current-Limiting Fuse. **H. L. Rawlins, A. P. Strom,** and **H. W. Graybill,** Westinghouse Electric and Manufacturing Company

40-145-ACO†. Load-Regulating Transformer for a High-Voltage Loop. **E. H. Bancker,** General Electric Company, **S. M. Hamill, Jr.,** and **J. W. Hanson,** Cincinnati Gas and Electric Company, and **M. H. Sauter,** General Electric Company.

9:00 a.m. Industrial Power Applications

40-146. The Application of Ignitrons to Resistance-Welding Control. **M. E. Bivens,** General Electric Company

40-142. Two New Methods of Accelerating Electric Motors Automatically. **John D. Leitch,** The Electric Controller and Manufacturing Company

40-147. Testing of Elevator Oil Buffers by Electrical Means. **E. E. Kimberly,** Ohio State University

40-148. Fault Voltage Drop and Impedance at Short-Circuit Currents in Low-Voltage Circuits. **O. R. Schurig,** General Electric Company

DP.* Aircraft Vibration Testing Equipment. **R. F. Conner,** United States Army Air Corps

DP.* Airdrome Lighting. **W. T. Harding,** United States Army Air Corps

Friday, October 11

9:00 a.m. Selected Subjects

DP.* Progress in Two-Way Radio for Utilities, Police, and Similar Services. **F. M. Link, F. M. Link** Radio Company

40-149-ACO.† Short-Wave Diathermy Apparatus and Frequency-Control Possibilities. **C. K. Gieringer,** The Liebel-Flarsheim Company

40-156. Radiant Heat—A Full-Fledged Industrial Tool. **P. H. Goodell, C. M. Hall** Lamp Company

40-150. A Comparison of the Relative Efficiency of the Schafer and Pole-Top Methods of Artificial Respiration. **W. B. Kouwenhoven, D. R. Hooker,** and **O. R. Langworthy,** The Johns Hopkins University

DP.* Aircraft Engine Starters. **H. L. Carpenter,** United States Army Air Corps

9:00 a.m. Single-Phase Motors

J. L. Hamilton, presiding

40-139. The Use of Auxiliary Impedances in the Single-Phase Operation of Polyphase Induction Motors. **R. W. Ager,** University of California

40-140. The Cross-Field Theory of the Capacitor Motor. **A. F. Puchstein** and **T. C. Lloyd,** Robbins and Myers, Inc.

40-151-ACO.† Single-Phase Motor Theory—A Correlation of the Cross-Field and Revolving-Field Concepts. **C. T. Button,** The Holtzer-Cabot Electric Company

40-152. Performance Calculations on Repulsion Motors. **P. H. Trickey,** Diehl Manufacturing Company

40-153. Performance Calculations on Capacitor Motors. **P. H. Trickey,** Diehl Manufacturing Company

40-141. Single-Phase Induction-Motor Performance Calculation. **F. S. Himebrook,** The Master Electric Company

40-154. Design Factors Involved in the Design of Domestic Motored Appliances. **L. C. Packer,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Conference on Motors

This conference will consist of short presentations and extemporaneous discussions on some of the practical problems involved in the design, manufacture, and operation of electric motors. The conference is planned to supplement the formal papers presented in the morning session on single-phase motors, which deal largely with the theoretical aspects of motor design.

*DP: District paper, for which no advance copies are available; not intended for publication in TRANSACTIONS.

†ACO: Advance copies only available; not intended for publication in TRANSACTIONS.

Meetings and papers: L. L. Bosch, *chairman;* C. K. Gieringer, C. M. Mason, W. C. Osterbrock, P. H. Rutherford, P. B. Stewart.

Hotels and registration: V. G. Rettig, *chairman;* Wm. Breuning, and C. D. Coy.

Student sessions: L. R. Culver, *chairman;* Wynne Gulden, Don Michael.

Publicity and attendance: A. C. Burroway, *chairman;* F. J. Breen, Jr., L. J. Fritz, Elmer Nuezel.

Inspection and transportation: J. A. Noertker, *chairman;* A. B. Cavaguaro, J. L. Clagett, E. G. Schlup.

Finance: M. S. Schneider, *chairman;* H. E. Deardorff, E. J. Jonas, O. C. Schlemmer.

Entertainment: Cowden Fortenbaugh, *chairman;* N. J. Bukey, Lincoln Higgins, C. W. Parsons.

Women's entertainment: Mrs. J. A. Noertker, *chairman;* Mrs. L. L. Bosch, Mrs. J. T. Bronson, Mrs. A. C. Burroway, Mrs. G. W. Coulehan, Mrs. H. E. Deardorff, Mrs. R. S. Fields, Mrs. C. K. Gieringer, Mrs. C. F. Lee, Mrs. Eric O'Hara, Miss Julia Surnbrock.

National • • • •

Changes in Institute Committees

By recent actions of the board of directors, two new technical committees have been created, the names and scope of two other technical committees altered, and one committee changed in status from technical to general.

The new technical committees are the committee on domestic and commercial applications, the scope of which will include applications of electricity to refrigeration, and the committee on air transportation. At the same time that the latter committee was established, the committee on transportation was changed to the committee on land transportation, and the committee on applications to marine work was changed to the committee on marine transportation.

The committee on research, formerly a

technical committee, is now a general committee. This change is expected to eliminate some duplication of the work of other technical committees, which are concerned with research in their various fields; to stimulate research which concerns the Institute; and to give research in electrical engineering a more general and representative status than it has had in the past.

Membership for 1940–41 in these and other Institute committees is listed on pages 377–81.

Board of Directors Meets

The regular meeting of the AIEE board of directors was held at Institute headquarters, New York, N. Y., August 2, 1940. As a result of a report of the committee on planning and co-ordination concerning a suggestion previously referred to that committee for the establishment by the Institute of a technical committee on the subject of electricity in aviation, the board voted to establish a new technical "committee on air transportation," and to change the name of the committee on transportation to "committee on land transportation," and that of the committee on applications to marine work to "committee on marine transportation."

Upon request of the Engineers' Council for Professional Development, the board approved a change in the charter of ECPD to admit the Engineering Institute of Canada as a participating body of ECPD.

Announcement was made of the appointment by the president of Institute committees for the administrative year beginning August 1, 1940 (see list, pages 377–81).

The following actions also were taken on committee appointments:

Edison Medal committee

Appointments confirmed:

L. W. W. Morrow, chairman, 1940–41

Karl T. Compton, W. D. Coolidge, J. M. Thomson, five-year term beginning August 1, 1940

Elected by board from own membership:

T. F. Barton, R. E. Hellmund, D. C. Prince, two-year term beginning August 1, 1940

Lamme Medal committee

Appointments confirmed:

Mark Eldredge, R. E. Hellmund, M. J. Kelly, three-year term beginning August 1, 1940

Charles LeGeyt Fortescue Fellowship committee

Reappointments confirmed:

C. A. Powel, D. C. Prince, three-year term beginning August 1, 1940

Institute representatives on various organizations were reappointed as follows:

Marston Medal board of award

Bion J. Arnold, four-year term beginning August 1, 1940

ECPD

F. Ellis Johnson, three-year term beginning October 1940

UET, Inc., board of trustees

H. R. Woodrow, four-year term beginning October 1940 (Mr. Woodrow died August 12, 1940; see page 375 for obituary item.)

UET, Inc., Library board

W. A. Del Mar, four-year term beginning October 1940

Engineering Foundation, research procedure committee

L. W. Chubb, one-year term beginning October 1940

The following local honorary secretaries of the Institute were reappointed for the two-year term beginning August 1, 1940:

V. J. F. Brain, Australia
A. S. Garfield, France
V. F. Critchley, Northern India
M. N. Iengar, Southern India
W. Elsdon-Dew, Transvaal

Other actions taken included the following:

Minutes of the meeting of the board of directors held June 27, 1940, were approved.

A report of a meeting of the board of examiners held July 25, 1940, was presented and approved. Upon recommendation of that board, the following actions were taken: 11 applicants transferred to the grade of Fellow; 41 transferred and 21 elected to the grade of Member; 102 elected to the grade of Associate; 18 Students enrolled.

Expenditures in July, amounting to $30,926.13, were reported by the chairman of the finance committee and were approved by the board.

Those present were:

President—R. W. Sorensen, Pasadena, Calif.

Junior past presidents—F. Malcolm Farmer and John C. Parker, New York, N. Y.

Vice-presidents—J. W. Barker, New York, N. Y.; K. L. Hansen, Milwaukee, Wis.; Everett S. Lee, Schenectady, N. Y.; Fred R. Maxwell, Jr., University, Ala.; C. T. Sinclair, Pittsburgh, Pa.; A. LeRoy Taylor, Salt Lake City, Utah; J. M. Thomson, Toronto, Ont.; A. L. Turner, Omaha, Nebr.

Directors—T. F. Barton, C. R. Beardsley, and H. S. Osborne, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Memphis, Tenn.; R. E. Hellmund, East Pittsburgh, Pa.; L. R. Mapes, Chicago, Ill.; F. J. Meyer, Oklahoma City, Okla.; D. C. Prince, Schenectady, N. Y.; R. G. Warner, New Haven, Conn.

National treasurer—W. I. Slichter, New York, N. Y.

National secretary—H. H. Henline, New York, N. Y.

Lamme Medal Nominations

Attention is called again to the opportunity open to any Institute member to submit nominations for the 1940 AIEE Lamme Medal. All nominations must be received not later than December 1. For further particulars see ELECTRICAL ENGINEERING, June 1940, page 250. The 1939 Medal was awarded to Norman W. Storer, retired consulting railway engineer, Westinghouse Electric and Manufacturing Company.

District • • • •

District 4 Executive Committee Meets at Swampscott

Meeting, June 26, 1940, at the New Ocean House, Swampscott, Mass., during the Institute's recent summer convention, the executive committee of the Southern District (4) discussed plans for the District meeting authorized by the board of directors to be held in New Orleans, La., in the fall of 1941. Co-operation of Section chairmen was urged to encourage attendance and technical papers for the meeting from members in the District. The next District conference on student activities will be held at Tuscaloosa, Ala., in the spring of 1941, it was announced. The interest of the Georgia Section in having the 1942 AIEE summer convention held at Atlanta was expressed.

Other matters discussed included state registration laws for engineers and the problems encountered in forming the new South Carolina Section, particularly questions of eligibility and local members.

Those present were:

Delegates: F. R. Maxwell, Jr., vice-president; A. S. Hoefflin, secretary; W. J. Miller, student counselor; W. W. Hill, Alabama; K. B. Hapgood, East Tennessee; Joseph Weil, Florida; J. O'D. Shepherd, Georgia; J. M. Houchens, Louisville; R. J. Biegel, Memphis; B. M. Anthony, Muscle Shoals; E. B. Mabson, New Orleans; G. O. Bason, North Carolina; T. F. Ball, South Carolina; F. W. Smith, Virginia.

Others: Mark Eldredge, past vice-president, Memphis; C. A. Perkins, B. H. McCoin, J. E. Housley, R. W. McEver, all of East Tennessee.

Future AIEE Meetings

Middle Eastern District Meeting
Cincinnati, Ohio, October 9–11, 1940

Winter Convention
Philadelphia, Pa., January 27–31, 1941

Great Lakes District Meeting
Fort Wayne, Ind., April 1941

North Eastern District Meeting
Rochester, N. Y., May 1941

Summer Convention
Toronto, Can., June 16–20, 1941

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained on payment of price indicated to the AIEE order department, 33 West 39th Street, New York, N.Y.

The papers previewed in this issue will be presented at the Middle Eastern District meeting, Cincinnati, Ohio, October 9–11, 1940.

Electrical Machinery

40-152—Performance Calculations on Repulsion Motors; *P. H. Trickey (M'36).* *10¢.* A method of calculating the performance of repulsion motors is developed for the purpose of predetermining the torques and currents, especially for repulsion-start induction-run motors during the starting period. The method is based on the cross-field theory presented by H. R. West. It is developed along similar lines to the single-phase calculation method of C. G. Veinott, and is intended for use in connection with it. The paper presents also the results of investigation showing the effects of varying the several motor constants, and a method of determining the effect of brush resistance.

40-153—Performance Calculations on Capacitor Motors—Part I. The Revolving Field Theory; *P. H. Trickey (M'36).* *10¢.* A method is presented whereby the equations of capacitor motor performance calculation as developed by W. J. Morrill are arranged in a calculation sheet for use in routine design work. W. J. Morrill's classic paper on "The Revolving Field Theory of the Capacitor Motor", presented in 1929,

gave the complete equations for calculating the performance and torque of a capacitor motor at any value of slip. The equations are straightforward, but involve vector operations, and are rather slow for routine design work. Since 1929, many engineers have used the method, and have devised different methods of doing the many numerical operations necessary to obtain a final solution. These have varied from using the equations directly as written, making each vector operation as necessary, to working up a calculation sheet where all operations were numerical. Most engineers involved in motor design work, however, feel that any great number of vector operations in the midst of routine work brings considerable risk of errors, and like to avoid vectors where possible. The writer has developed a calculation sheet for using these formulas, where all the operations except the last in calculating the currents are performed without vectors. This seems to be a fairly satisfactory compromise, and has worked out quite well in practice.

40-141—Single-Phase Induction-Motor Performance Calculation; *F. S. Himebrook* (*M'39*). *10¢.* In the manufacture of electrical machines it is always desirable to calculate the performance of a machine before its construction to determine whether or not it will meet the specifications. This paper describes the development of a method which may be used to plot, as families of curves, the quantities necessary for the performance calculation of single-phase induction motors. The results obtained by the use of the curves indicate that when the original work is carefully carried out considerable time may be saved and results obtained which are as accurate as usually might be obtained by the construction of a special diagram for each motor.

40-138—The "Black-Band" Method of Commutation Observation; *T. W. Schroeder* (*A'37*) *and John C. Aydelott* (*M'32*). *10¢.* Good commutation is essential for the reliable performance of d-c machines with low maintenance costs. As an aid to the commutation adjustment of machines in the factory, or in the field, a systematic test procedure has been found useful on large machines to indicate certain features of the machine's adjustment, notably the commutating field strength and brush position. This information is obtained directly from curves known as "black bands" or "buck-and-boost curves" plotted from test observations. The significance and interpretation of these curves in terms of machine adjustments, differential between commutation-reactance voltage and voltage induced by interpole flux are presented and results of observations on machines for special service are given.

40-140—The Cross-Field Theory of the Capacitor Motor; *A. F. Puchstein* (*M'27*) *and T. C. Lloyd* (*A'31*). *10¢.* The cross-field theory has been successfully applied to plain single-phase induction-motor analyses, but heretofore no application of this theory has been made to the capacitor motor. This paper is an exposition of such an analysis. A number of examples have been calculated, one of which is shown. The final data are tabulated along with results on the same motor as obtained through other analyses. Considerable experience in handling these equations has led the writers to the belief that for time involved and complexity of calculation there is little to choose between the double-revolving and the cross-field theories.

40-139—The Use of Auxiliary Impedances in the Single-Phase Operation of Polyphase Induction Motors; *Raymond W. Ager* (*A'24*). *10¢.* If a polyphase motor is operated from a single-phase line and auxiliary impedances are used to shift the phase currents and the motor terminal voltages so that the currents and voltages of the motor are properly balanced both as to phase and magnitude, the motor willl operate as though it were supplied from its normal polyphase line. Because the motor current and power factor both change as the speed changes, the impedances required also must change with the motor speed. This study of the impedance variations was made with the idea that general conclusions regarding these impedances might be drawn. The results of this analysis show that no appropriate values of impedance can be found for the full-speed running conditions which will give polyphase performance for more than a single point.

Electronics and Electric Welding

40-146—The Application of Ignitrons to Resistance-Welding Control; *M. E. Bivens* *10¢.* The object of this paper is to review ignitron characteristics and to point out the operating principles which should be considered in order to insure successful applications. In the field of resistance-welding control the ignitron has been proved to possess a combination of characteristics, such as high current-carrying capacity, efficiency, ease of control, reliability, instantaneous operation, no moving parts, quietness, and long life, unequaled by any other device. This brief description of its design and operation may be desired by those who have not followed its development closely or realized its usefulness as exemplified by its expansion of the field of resistance-welding control.

Industrial Power Applications

40-142—Two New Methods of Accelerating Electric Motors Automatically; *J. D. Leitch* (*A'38*). *10¢.* The first of the two methods discussed in this paper is particularly applicable to a-c slip-ring motors. Series resonance circuits responsive to the variation in rotor frequency with motor speed provide a means of accelerating the motor automatically, while a series-parallel resonance circuit similarly connected to the rotor can be used to protect the motor when "plugged" or suddenly reversed. The sensitive response of the latter circuit within a narrow frequency range makes possible its use as a "zero-speed" switch. The second method can be used with any type of motor. A neon-tube timing-circuit measures the time intervals between the closures of accelerating contactors. One "timer" can be used for all steps of acceleration, with or without separate time adjustment. For a-c motor control, the introduction of a current transformer and a rectifying circuit makes possible the obtaining of time intervals which are increased automatically with increase in motor load. Such a scheme is often referred to as "time-current" acceleration, in order to distinguish it from "constant-time" acceleration, where the time interval is independent of the load.

Instruments and Measurements

40-147—Testing of Elevator Buffers by Electrical Means; *E. E. Kimberly* (*A'34*). *10¢.* The purpose of an elevator buffer is to stop the elevator in event it reaches the bottom of its hoistway out of control. To prevent injury to its occupants, the rate of stopping must not exceed $2^1/_2$ times gravity or about 80 feet per second for more than $^1/_{25}$ second. The tests on a buffer should be such that the velocity at which the elevator strikes the buffer and the rate of deceleration at every point in the piston stroke may be determined. If the buffer contains oil, it is important for the designer to know also the oil pressure at every point in the stroke. To determine the striking velocity of the elevator car, a magnetic pick-up coil and grooved iron rod are used. The oil-pressure gauge consists of an oil-pressure cylinder and a carbon pile calibrated in resistance versus pressure.

Power Transmission and Distribution

40-137—The Effect of Overexciting Transformers on System Voltage Wave Shapes and Power Factor; *J. W. Buller* (*M'38*) *and E. B. Pope* (*A'38*). *10¢.* Measurements of harmonics made by the authors on various systems in the United States show in general that the harmonic voltages increase in magnitude as the measurements are made farther and farther from the generating stations. This indicates that transformer exciting currents probably have more effect on system wave shapes than is usually believed. Some of the conclusions are that the over-all system power factor can be materially reduced by exciting currents resulting from *excessive* overexcitation of the majority of the transformers, and that the use of capacitors and reactors in series for the dual purpose of power-factor and wave-form improvement provides a simple, effective, and economically sound method of coping with the problems presented by the overexcitation of transformers.

Standards • • •

Standards Manual

In seeking ways and means by which it could be of greatest service in furthering the development of electrical standardization, the AIEE standards committee during the past year decided to develop a "standards manual". This manual, when completed, will serve as a guide for AIEE standardization work. Two sections are of particular general interest, as they outline two of the most promising lines of activity; these are the sections dealing with "Basic Guiding

Standards" and "Test Codes", which are given here in full.

BASIC GUIDING STANDARDS

Since specific apparatus standards of the more commercial type are prepared by other agencies, such as American Standards Association, National Electrical Manufacturers Association, Edison Electric Institute, etc., the Institute, aside from co-operating with these agencies, can best serve the industry by devoting its attention to certain scientific standards and to basic standards serving as guides for other standardizing bodies. The 1940 revision of AIEE Standards No. 1, "General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus," has been modified to serve as a basic guiding standard. In this case, the standard proper outlines a method for deriving standards based on temperature rises. It also gives specific values for temperature rises which may be properly applied to a large percentage of apparatus and it suggests various methods of determining temperature rises and their preferred fields of application. At the same time it freely recognizes that technical or economic considerations may make departures from the values or methods given not only permissible but desirable for many specific types of apparatus or applications. However, in order to avoid the use of too many different values, it gives a table of preferred values, to be used in temperature-rise standards whenever possible. Other important parts of the standard contain definitions for such items as the various classes of insulation, ambient temperature, etc., which preferably should be used uniformly in all other standards for apparatus. In other words, an attempt has been made, without assuming any mandatory attitude, to guide other standardizing agencies with the intent of furthering the development of a free but co-ordinated system of electrical standards.

Inasmuch as this standard is to serve as a guide, it has been considered advisable to give in a preface basic considerations, such as general concepts, economic considerations, etc., which should assist in the interpretation of the standard proper. For similar reasons, an appendix was added, giving data that should be helpful in the preparation of standards and their application. In this particular standard, statistical temperature data for the United States and Canada are given and also a bibliography of publications dealing with temperature-rise problems in electrical machines and apparatus.

It is hoped that this brief outline will assist in the preparation of similar basic and guiding standards by the Institute.

TEST CODES

One of the most useful standards activities of the Institute during recent years has been the preparation of test codes and increased activity of this nature seems desirable.

Test codes can be of two classes, namely:

1. Codes applying to specific types of apparatus, conductors, etc., such as induction motors, synchronous motors, d-c machines, cables, etc.

2. Master codes relating to test methods for certain quantities common to many types of apparatus, etc. A test code for apparatus noise measurement is now available. Other master codes might be worked out for

(a) Method for resistance measurements
(b) Method for insulation testing
(c) Test methods for telephone interference
(d) Test methods for radio interference
(e) Test methods for determining temperature rises of machines and apparatus

These master test codes should be prepared in such a way that they can be referred to in whole or in part in any of the apparatus test codes, and also so that any master code or parts of a code can be used as an integral part of apparatus test codes. Considerable flexibility in this respect is desirable, because it is difficult to include everything relating to one line of apparatus in the test code for that apparatus without making it unduly bulky. On the other hand, it is inconvenient if an apparatus test code makes reference to a great many master codes. Those preparing apparatus test codes should therefore be able to choose the most advantageous compromise for each particular case.

Test codes in general should be confined to the description of test methods, although in some cases guidance for the interpretation of test results may be helpful. The codes should avoid the inclusion of standards provisions such as limiting values, ratings, etc. If in exceptional cases the inclusion of such data seems necessary either for convenience or clarification, it should be given in the form of footnotes and with definite identification of the standard quoted. Reference to specific standards in footnotes may also be justified at times.

In general, test codes should be issued as AIEE standards, although their adoption by the American Standards Association may be approved whenever desirable.

Protector Tubes. Report No. 24 on "Proposed Standards for Protector Tubes" is now available for purposes of criticism and the general information of the industry. This has been prepared by a subcommittee of the AIEE committee on protective devices, working under the chairmanship of I. W. Gross, American Gas and Electric Company. The standards apply to all types of protector tubes designed to limit voltage surges on 60-cycle a-c power circuits. They do not apply to special types of protector tubes used to protect transformers. As this proposed standard is in report form copies may be obtained without charge by writing AIEE headquarters, 33 West 39th Street, New York, N. Y.

Personal • • •

G. W. Faller (M'36) has been elected president of the Public Service Company of Colorado, Denver. He was born at North Freedom, Wis., April 16, 1878, and in 1898 was graduated from the United States Naval Academy where he had taken the engineers' course. Following five years' service as a commissioned officer in the Navy, he resigned to enter the employ of the Madison (Wis.) Gas and Electric Company. In 1905 he became engineer of gas distribution for the Denver Gas and Electric Company (later Denver Gas and Electric Light Company), advancing to the position of assistant superintendent in charge of gas and steam heat operations. He went with the City Light and Water Company, Amarillo, Tex., in 1913, as general superintendent, later becoming vice-president and general manager, and serving during the same period (1913–23) as treasurer and vice-president of the Amarillo Street Railway Company. From 1923 to 1930 he was associated with Denver Gas and Electric Light Company and Public Service Company of Colorado as assistant manager, director of the Doherty Training School, and vice-president. He was district manager of Henry L. Doherty and Company and of Alpha Distributors, Inc., 1930–34. Since 1934 he had been vice-president and general manager of Public Service Company of Colorado.

J. H. Gardner, Jr. (A'25, M'34) major, Signal Corps, United States Army, has been appointed director of the Aircraft Radio Laboratory, Wright Field, Dayton, Ohio. He was born at Altamont, N. Y., October 10, 1893, and received the degrees of bachelor of science in electrical engineering, 1913, and master of science, 1915, from Union College, and that of master of science in electrical engineering from Yale University in 1924. From 1913 to 1917 he was employed by the General Electric Company, first in the test course and later in the light engineering department, at Schenectady, N. Y., and Chicago, Ill. He entered the United States Army in 1917, becoming a radio and telephone officer in the Field Artillery, and from 1919 to 1921 was with the Intelligence Section of the American forces in Germany. He was transferred to the Signal Corps in 1921, in 1925 became assistant to signal officer, Fifth Corps Area, Columbus, Ohio, and in 1926 executive officer in charge of research and engineering in the office of the chief signal officer, Washington, D. C. In 1931 he became executive officer of the Signal Corps Laboratories, Fort Monmouth, N. J., later returning to the office of the chief signal officer in Washington. He had been executive officer of the Aircraft Radio Laboratory before being appointed director.

C. E. Stryker (A'21, F'35) formerly partner in the management engineering firm of McKinsey, Keraney, and Company, Chicago, has been appointed vice-president and assistant to the president of the Nordberg Manufacturing Company, Milwaukee, Wis. Born at Chicago, Ill., February 27, 1897, he received the degree of bachelor of science in electrical engineering from Armour Institute of Technology in 1917 and that of electrical engineer in 1924. He was a testing engineer for Commonwealth Edison Company, 1917–19; engineer and purchasing agent for the Ozone Pure Airifier Company, 1919–21; assistant electrical engineer, Underwriters Laboratories, 1922–23; and in 1923 became electrical engineer for Fansteel Products Company, Inc., all of Chicago. From 1920 to 1924 he was concurrently assistant professor of electrical engineering at Armour Institute of Technology. He continued with the Fansteel company until 1935, becoming manager of the industrial division and later chief engineer. He had been with McKin-

sey, Kearney, and Company for five years, becoming a partner in 1938. He is also a member of the Society of Automotive Engineers.

E. F. Scattergood (A'08, F'13) has retired as general manager and chief electrical engineer of the Bureau of Power and Light, City of Los Angeles, Calif. He will be retained for five years in an advisory capacity. Born April 9, 1871, near Burlington, N. J., he received the degrees of bachelor of science, 1893, and master of science, 1896, from Rutgers University, and that of master of mechanical engineering from Cornell University in 1899. From 1899 to 1901 he was professor of physics and electrical engineering at Georgia School of Technology, Atlanta. He was a special engineer in the joint electrical engineering office of the Pacific Light and Power, Pacific Electric Railway, and Los Angeles Railway companies at Los Angeles, 1902–06, and for the next three years had a consulting office in that city. In 1909 he became chief electrical engineer for the City's Bureau of Aqueduct Power, and in 1911 electrical engineer for the Department of Public Service. When the Bureau of Power and Light was created he became its chief electrical engineer and general manager, and has held those positions ever since.

H. C. Gardett (A'07, M'19) has been appointed chief electrical engineer and general manager of the Bureau of Power and Light of the City of Los Angeles, Calif. Born March 2, 1878, at Poso Flat, Calif., he received the degree of bachelor of science from the University of California in 1904. During 1904 he was employed on electrical jobs by R. S. Mason, consulting engineer, and in 1905 went to work for the Pacific Electric Railway Company, Los Angeles, as meter inspector, later becoming foreman. In 1907 he entered consulting practice in Los Angeles under E. F. Scattergood (A'08, F'13), and in 1909 became assistant to Mr. Scattergood for the Los Angeles Bureau of Aqueduct Power. He became assistant electrical engineer in 1912 for the city's Department of Public Service, and design and construction engineer of the Bureau of Power and Light in 1917. For several years he had been assistant chief electrical engineer and assistant general manager. **Roy Martindale** (M'21) formerly electrical engineer in charge of operations, Bureau of Power and Light, has been appointed assistant chief electrical engineer. A graduate (1906) of Purdue University, he was employed by General Electric Company, Schenectady, N. Y., and the Washington Water Power Company, Spokane, before being employed by the City of Los Angeles in 1911. He became assistant operating engineer of the Bureau of Power and Light in 1920 and electrical engineer in charge of operations in 1939.

Gano Dunn (A'91, F'12) president, J. G. White Engineering Corporation, New York, N. Y., has been appointed chairman of the advisory power committee organized by the National Defense Advisory Commission to co-ordinate electric-power supplies for industries engaged in national defense production. Doctor Dunn was a member of the engineering committee of the Council of National Defense during the World War. A biographical sketch of him appeared in the November 1939 issue, page 489. **C. W. Kellogg** (A'19, M'23) president, Edison Electric Institute, New York, N. Y., has been appointed a member of the power committee and has been granted a leave of absence from his present duties to serve in that capacity.

D. C. Jackson (A'87, F'12) professor emeritus of electrical engineering, Massachusetts Institute of Technology, Cambridge, has been appointed chairman of a new committee of American Engineering Council, designated to prepare a code of ethics for the engineering profession (*EE, Aug. '40, p. 328*). Doctor Jackson, who was president of the Institute 1910–11, is chairman of its committee on code of principles of professional conduct.

F. B. Jewett (A'03, F'12) vice-president, American Telephone and Telegraph Company, and president, Bell Telephone Laboratories, New York, N. Y., has been appointed a member of the National Defense Research Committee, and is serving as chairman of the subcommittee on communication and transportation.

W. H. Harrison (A'20, F'31) vice-president and chief engineer of the American Telephone and Telegraph Company, New York, N. Y., has been appointed director of the construction division of the production division of the National Defense Advisory Commission.

P. J. Kiel (A'37) has been transferred from Chase Brass and Copper Company, Cleveland, Ohio, to Kennecott Wire and Cable Company, as cable sales engineer with headquarters at Phillipsdale, R. I. Both companies are subsidiaries of Kennecott Copper Corporation.

J. W. Morrison (A'09, M'32) vice-president and chief engineer, Rochester Telephone Corporation, Rochester, N. Y., has been nominated as a director of the Rochester Engineering Society for 1940–43. He is a past chairman of the AIEE Rochester Section.

Joseph Gladis (A'27) former electrical designer, New England Power Service Company, Boston, Mass., is now employed in the switchboard division of the engineering department of the Roller-Smith Company, Bethlehem, Pa.

L. D. Smullin (A'37) formerly an engineer for the Farnsworth Television and Radio Corporation, Fort Wayne, Ind., is now employed in the research department of the Scintilla Magneto division, Bendix Aviation Corporation, Sidney, N. Y.

Ward Harrison (F'36) director of engineering, lamp department, General Electric Company, Cleveland, Ohio, recently was awarded the honorary degree of doctor of illuminating engineering by the Case School of Applied Science.

Douglas Montgomery (A'26) formerly assistant electrical engineer, Illinois Iowa Power Company, Champaign, Ill., is now employed as senior layout draftsman, electrical and radio group, Vega Airplane Company, Burbank, Calif.

E. A. Armstrong (A'13, M'32) manager of power sales, Public Service Company of Northern Illinois, Chicago, Ill., has been elected chairman of the board of directors of the Great Lakes Power Club for 1940–41.

E. O. Shreve (A'06) vice-president, General Electric Company, Schenectady, N. Y., has been elected a vice-president of the American Management Association for a second term.

H. P. Liversidge (A'12, M'17) president, Philadelphia Electric Company, Philadelphia, Pa., recently was awarded the honorary degree of doctor of engineering by Stevens Institute of Technology.

H. C. Blackwell (A'09) president, Cincinnati Gas and Electric Company, Cincinnati, Ohio, recently was awarded the honorary degree of doctor of engineering from Purdue University.

E. B. Currie (A'36) has been made manager of the Binghamton office of the General Electric Company. He has been with the company since 1925 and before the present appointment was in the Rochester office.

O. J. Moses (A'35) formerly engineer, Lynn (Mass.) Gas and Electric Company, is now employed in a similar capacity by the Hartford (Conn.) Electric Light Company.

Saul Dushman (A'13) assistant director of the research laboratory, General Electric Company, Schenectady, N. Y., recently was awarded the honorary degree of doctor of science by Union College.

M. H. Pollyea (A'37) formerly junior engineer, C. J. Tagliabue Manufacturing Company, Brooklyn, N. Y., is now employed as an instrument engineer by the Sun Oil Company, Toledo, Ohio.

B. C. J. Wheatlake (A'16), district manager, General Electric Company, Salt Lake City, Utah, has been elected president of the Salt Lake City Optimist Club.

L. G. Henry (A'40) has been employed as assistant to the chief engineer, alkali division, Canadian Industries, Ltd., Shawinigan Falls, Ont., Can.

J. W. Carpenter (M'35) president, Texas Power and Light Company, Dallas, was awarded the honorary degree of doctor of laws by Texas Technological College.

C. A. Pfleiderer (M'39) equipment engineer, Indiana Bell Telephone Company, Indianapolis, has been appointed building and equipment engineer of that company.

Obituary • • •

Harry Ray Woodrow (A'12, F'23) vice-president in charge of design, planning, and inventory, Consolidated Edison Company of New York, Inc., New York, N. Y., died August 12, 1940. He was born in Minnesota, April 15, 1887, and received the de-

grees of bachelor of science, Drake University, 1909 and master of science, University of Illinois, 1911. He later received the degree of doctor of laws from Drake. In 1911 he joined the staff of the New York (N. Y.) Edison Company as assistant to the chief electrical engineer, and in 1917 was given the title of assistant chief electrical engineer. He went with Stone and Webster, Inc., Boston, Mass., in 1920 as electrical engineer, remaining with that company about two years and with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as general engineer for part of a year, before becoming assistant electrical engineer for the Brooklyn (N. Y.) Edison Company late in 1922. He was made electrical engineer in 1926 and vice-president in 1932, and became a director of the company in 1935. He was elected a vice-president of Consolidated Edison in 1937. He served the Institute as a director 1931–35 and had represented the Institute on United Engineering Trustees, Inc., since 1934. He was a member of the committee on Institute policy and formerly had been a member of the committees on membership, protective devices (chairman 1921–25), standards, power transmission and distribution (chairman 1928–30), economic status of the engineer, and of the publication and Edison Medal committees. He was also active in the former National Electric Light Association and in the Association of Edison Illuminating Companies and the American Standards Association, and was also a member of Sigma Xi and Phi Beta Kappa.

Walter Everette Brown (A'02) electrical engineer, National Bureau of Standards, Washington, D. C., died May 13, 1940. He was born at Stamford, Conn., May 20, 1874, and received the degree of electrical engineer from Lehigh University in 1897. Following graduation he was employed by the New York and New Jersey Telephone Company and continued with the company until 1910, advancing to the position of equipment engineer. He then became chief inspector for the division of telephony and telegraphy of the New York State Public Service Commission. From 1912 to 1914 he was general superintendent and engineer of the Buelle Company, manufacturer of fire doors, and in 1914–15 held the same position with the Rexolite Company. He was district manager of the St. Louis Fire Door Company 1915–16, vice-president and engineer of the Fowler Bottling Machine Company 1916–18, and became associate electrical engineer for the Bureau of Standards in 1918, later becoming electrical engineer. His service to the Bureau included extensive work in cooperation with the Bureau of Prisons on special telephone equipment for Federal penitentiaries.

Frank Prague Colville (M'30) Cincinnati manager, Westinghouse Electric and Manufacturing Company, Cincinnati, Ohio, died July 20, 1940. He was born at Covington, Ky., April 20, 1883, and received the degree of bachelor of science from the University of Cincinnati in 1904. From 1904 to 1906 he was employed in the drafting room of the Bullock Electric Company, Norwood, Ohio, and during the following year was assistant to W. G. Franz, Cincinnati consulting engineer. From 1907 to 1910 he was with the Western Electric Company, spending a year in the shop course in Chicago, Ill., and two years on the sales force in Cincinnati. He was vice-president of the Reno Kaetker Electric Company, Cincinnati, from 1910 to 1918, and after a year as lieutenant in the Engineers Corps of the United States Army, was employed by Eaton Rhodes and Company in charge of the firm's Ashland, Ky., office. He joined the Westinghouse company in 1922 as a salesman in the Louisville, Ky., office. He was made manager of the Dayton, Ohio, office in 1925, manager of the Dayton and Columbus, Ohio, offices in 1928, and manager of the Cincinnati office in 1930.

William Louis Garrels (A'95) consulting engineer, Kirkwood, Mo., died recently, according to information just received at Institute headquarters. He was born at St. Louis, Mo., February 12, 1872, and attended Washington University and Cornell University. He received from the latter institution the degrees of mechanical engineer, in 1893, and master of mechanical engineering, in 1894, having specialized in electrical engineering. Following graduation he entered the student course of Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa. During 1895–96 he was representative of the Fruin-Bambrick Construction Company, St. Louis, on the construction of the Holyoke, Mass., stone dam. He had been engaged in private consulting practice since 1897. He held several United States patents, and was also a member of the Franklin Institute.

Robert John Parmenter (A'17, M'32) designing engineer, Public Service Company of Northern Illinois, Chicago, Ill., died July 26, 1940. He was born at Elmira, N. Y., September 10, 1890, and received the degree of bachelor of science in electrical engineering from Bucknell University in 1914. During the next two years he was employed by the Elmira Water Light and Railroad Company, first on appraisal work, later on construction and operation. He was an electrical draftsman for Sargent and Lundy, Chicago, Ill., 1916–17, and during 1917–19 served with the United States Army in France as a lieutenant in the Engineers Corps. He entered the employ of Public Service Company of Northern Illinois in 1919, as a draftsman, becoming purchasing engineer in 1924 and designing engineer in 1926.

Charles Jules Cosandey (A'27) instructor in physics, mathematics, and electrical engineering at Duluth Junior College, Duluth, Minn., died recently, according to information just received at Institute headquarters. He was born at Lucens, Vaud, Switzerland, October 31, 1894. He received the degree of bachelor of science in electrical engineering from the University of Minnesota in 1925, and that of master of science from Iowa State College in 1926. In 1925–26 he was an assistant and later instructor in electrical engineering at Iowa State College, Ames, and in 1926 he became instructor in radio engineering at the University of South Dakota, Vermillion. He had been an instructor at Duluth Junior College for more than ten years.

William Sherwood White (A'39) staff engineer, Bell Telephone Company of Pennsylvania, Philadelphia, died May 7, 1940. He was born May 28, 1905, at Philadelphia, and was graduated in 1928 from the Moore School of Electrical Engineering, University of Pennsylvania. He was employed by the Bell Telephone Company of Pennsylvania in 1929 as an engineering assistant on telephone transmission, and had been with the company continuously except for two years (1935–37) with the Diamond State Telephone Company as repairman on equipment maintenance. Since 1937 he had been a staff engineer assigned to cable and cable equipment studies.

Membership • •

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before September 30, 1940, or November 30, 1940, if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Drake, F. E., Jr., Rochester Gas and Electric Corporation, Rochester, N. Y.
Lytle, J. A., New England Power Service Company, Providence, R. I.
Peterson, C. H. (Member), Jackson and Moreland, Boston, Mass.

2. MIDDLE EASTERN

Finzi, L. A., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Harness, S. A., RFD 3, Federalsburg, Md.
Johnson, C. L. (Member), Rural Electrification Administration, Washington, D. C.
Kesecker, K. S., Navy Department, Washington, D. C.

3. NEW YORK CITY

Aberg, S. T., 101 Park Avenue, New York, N. Y.
Haines, A. B., Bell Telephone Laboratories, New York, N. Y.

4. SOUTHERN

Davis, D. H., South Carolina Power Company, Charleston.
Trotta, J. P. (Member), 3012 Morgan Street Tampa, Fla.

5. GREAT LAKES

Cleghorn, R. R., Bull Dog Electric Products Company, Detroit, Mich.
Ellithorn, H. B., University of Notre Dame, Notre Dame, Ind.
Helsey, R. R., Bull Dog Electric Products Company, Detroit, Mich.
Johnson, J. A., Chicago Bridge and Iron Company, Chicago, Ill.
Platz, E. T., Bull Dog Electric Products Company, Detroit, Mich.
Togesen, A. A., Bull Dog Electric Products Company, Detroit, Mich.

6. NORTH CENTRAL

Goulby, L. A., Westinghouse Electric and Manufacturing Company, Denver, Colo.

7. SOUTH WEST

Kilcrease, J. W., Southwestern Public Service Company, Amarillo, Tex.
Tolk, R., Southwestern Public Service Company, Amarillo, Tex.

9. NORTH WEST

Lee, C. B., 3201 46th Avenue, S.W., Seattle, Wash.

Total, United States, 21

Elsewhere

Fletcher, D., Admiralty, Bath, England.
Serwarey, J. S., V. and P. O., Sialba Majri, District of Ambala, India.

Total, elsewhere, 2

Officers and Committees for 1940-41

Officers

President

R. W. SORENSEN — Pasadena, Calif.
(Term expires July 31, 1941)

Junior Past Presidents

JOHN C. PARKER — New York, N. Y.
(Term expires July 31, 1941)

F. MALCOLM FARMER — New York, N. Y.
(Term expires July 31, 1942)

Vice-Presidents

District		
2	C. T. SINCLAIR	Pittsburgh, Pa.
4	F. A. MAXWELL, JR.	University, Ala.
6	A. L. TURNER	Omaha, Nebr.
8	H. W. HITCHCOCK	Los Angeles, Calif.
10	J. M. THOMSON	Toronto, Ont.

(Terms expire July 31, 1941)

	EVERETT S. LEE	Schenectady, N. Y.
3	J. W. BARKER	New York, N. Y.
5	K. L. HANSEN	Milwaukee, Wis.
7	J. L. HAMILTON	St. Louis, Mo.
9	A. LEROY TAYLOR	Salt Lake City, Utah

(Terms expire July 31, 1942)

Directors

C. R. BEARDSLEY — New York, N. Y.
VANNEVAR BUSH — Washington, D. C.
F. H. LANE — Chicago, Ill.
(Terms expire July 31, 1941)

L. R. MAPES — Chicago, Ill.
H. S. OSBORNE — New York, N. Y.
D. C. PRINCE — Schenectady, N. Y.
(Terms expire July 31, 1942)

MARK ELDREDGE — Worcester, Mass.
R. E. HELLMUND — East Pittsburgh, Pa.
F. J. MEYER — Oklahoma City, Okla.
(Terms expire July 31, 1943)

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Akron, Univ. of, Akron, Ohio	2	J. T. Walther
Alabama Polytechnic Inst., Auburn	4	W. W. Hill
Alabama, Univ. of, University	4	W. J. Miller
Alberta, Univ. of, Edmonton, Alberta, Can	10	E. G. Cullwick
Arizona, Univ. of, Tucson	8	J. C. Clark
Arkansas, Univ. of, Fayetteville	7	C. W. Janes
Armour Inst. of Tech., Chicago, Ill	5	E. H. Freeman
British Columbia, Univ. of, Vancouver	10	W. B. Coulthard
Brooklyn, Polytechnic Inst. of, Brooklyn, N. Y	3	A. B. Giordano
Brown Univ., Providence, R. I	1	F. N Tompkins
Bucknell Univ., Lewisburg, Pa	2	J. B. Miller
California Inst. of Tech., Pasadena	8	F. W. Maxstadt
California, Univ. of, Berkeley	8	C. F. Dalziel
Carnegie Inst. of Technology, Pittsburgh, Pa	2	G. R. Patterson
Case School of Applied Science, Cleveland, Ohio	2	J. R. Martin
Catholic Univ. of America, Washington, D. C	2	T. J. MacKavanagh
Cincinnati, Univ. of, Cincinnati, Ohio	2	L. R. Culver
Clarkson Col. of Technology, Potsdam, N. Y	1	A. R. Powers
Clemson Agricultural Col., Clemson, S. C	4	S. R. Rhodes
Colorado State Col. of A. & M. Arts, Fort Collins	6	F. B. Beatty
Colorado, Univ. of, Boulder	6	H. B. Palmer
Columbia Univ., New York, N. Y	3	G. T. Harness
Cooper Union, New York, N. Y	3	N. L. Towle
Cornell Univ., Ithaca, N. Y	1	W. W. Cotner
Denver, Univ. of, Denver, Colo	6	Chester Russell, Jr.
Detroit, Univ. of, Detroit, Mich	5	H. O. Warner
Drexel Inst. of Technology, Philadelphia, Pa	2	E. O. Lange
Duke Univ., Durham, N. C	4	W. J. Seeley
Florida, Univ. of, Gainesville	4	B. F. Smith
George Washington Univ., Washington, D. C	2	A. G. Ennis
Georgia School of Technology, Atlanta	4	T. W. Fitzgerald
Harvard Univ., Cambridge, Mass	1	J. D. Cobine
Idaho, Univ. of, Moscow	9	R. H. Hull
Illinois, Univ. of, Urbana	5	E. A. Reid
Iowa State Col., Ames	5	B. S. Willis
Iowa, Univ. of, Iowa City	5	G. F. Corcoran
Johns Hopkins Univ., Baltimore, Md	2	W. B. Kouwenhoven
Kansas State Col., Manhattan	7	R. G. Kloeffler
Kansas, Univ. of, Lawrence	7	R. J. W. Koopman
Kentucky, Univ. of, Lexington	4	Brinkley Barnett
Lafayette Col., Easton, Pa	2	F. W. Smith
Lehigh Univ., Bethlehem, Pa	2	N. S. Hibshman
Lewis Inst., Chicago, Ill	5	L. T. Anderson
Louisiana State Univ., Baton Rouge	4	W. D. Morris
Louisville, Univ. of, Louisville, Ky	4	J. M. Roberts
Maine, Univ. of, Orono	1	A. S. Hill
Marquette Univ., Milwaukee, Wis	5	E. W. Kane
Maryland, Univ. of, College Park	2	L. J. Hodgins
Massachusetts Inst. of Technology, Cambridge	1	Gordon S. Brown
Michigan Col. of Mining & Tech., Houghton	5	G. W. Swenson
Michigan State Col., E. Lansing	5	M. M. Cory
Michigan, Univ. of, Ann Arbor	5	J. S. Gault
Milwaukee School of Engg., Milwaukee, Wis	5	E. L. Wiedner
Minnesota, Univ. of, Minneapolis	5	J. H. Kuhlmann
Mississippi State Col., State College	4	H. C. Simrall
Missouri School of Mines and Met., Rolla	7	J. Stuart Johnson
Missouri, Univ. of, Columbia	7	R. B. Vaile
Montana State Col., Bozeman	9	E. W. Schilling
Nebraska, Univ. of, Lincoln	6	L. A. Bingham
Nevada, Univ. of, Reno	8	S. G. Palmer
Newark Col. of Engineering, Newark, N. J	3	C. H. Stephan
New Hamsphire, Univ. of, Durham	1	L. W. Hitchcock
New Mexico State Col., State College	7	M. A. Thomas
New Mexico, Univ. of, Albuquerque	7	R. W. Tapy
New York, Col. of the City of, New York	3	Harry Baum
New York Univ., New York	3	H. N. Walker
North Carolina State Col., Raleigh	4	R. S. Fouraker
North Dakota Agricultural Col., Fargo	6	H. S. Rush
North Dakota, Univ. of, Grand Forks	6	H. F. Rice
Northeastern Univ., Boston, Mass	1	R. G. Porter
Northwestern Univ., Evanston, Ill	5	E. W. Kimbark
Norwich Univ., Northfield, Vt	1	D. E. Howes
Notre Dame, Univ. of, Notre Dame, Ind	5	J. A. Northcott
Ohio Northern Univ., Ada	2	D. S. Pearson
Ohio State Univ., Columbus	2	R. E. Kimberly
Ohio Univ., Athens	2	W. M. Young
Oklahoma A. & M. Col., Stillwater	7	Albrecht Naeter
Oklahoma, Univ. of, Norman	7	C. T. Almquist
Oregon State Col., Corvallis	9	A. L. Albert
Pennsylvania State Col., State College	2	P. X. Rice
Pennsylvania, Univ. of, Philadelphia	2	Irven Travis
Pittsburgh, Univ. of, Pittsburgh, Pa	2	R. C. Gorham
Puerto Rico, Univ. of, Mayaguez	3	G. F. Anton
Pratt Institute, Brooklyn, N. Y	3	D. H. Wright
Princeton Univ., Princeton, N. J	2	A. E. Vivell
Purdue Univ., Lafayette, Ind	5	J. H. Bowman
Rensselaer Polytechnic Inst., Troy, N. Y	1	L. C. Holmes
Rhode Island State Col., Kingston	1	W. B. Hall
Rice Institute, Houston, Texas	7	J. S. Waters
Rose Polytechnic Inst., Terre Haute, Ind	5	C. C. Knipmeyer
Rutgers Univ., New Brunswick, N. J	3	F. P. Fischer
Santa Clara, Univ. of, Santa Clara, Calif	8	R. F. Peterson
South Carolina, Univ. of, Columbia	4	T. F. Ball
South Dakota State Col., Brookings	6	W. H. Gamble
South Dakota State School of Mines, Rapid City	6	L. O. Kammerman
Southern California, Univ. of, Los Angeles, Calif	8	J. K. Nunan
Southern Methodist Univ., Dallas, Texas	7	S. G. Lutz
Stanford Univ., Stanford University, Calif	8	H. H. Skilling
Stevens Inst. of Technology, Hoboken, N. J	3	H. C. Roters
Swarthmore Col., Swarthmore, Pa	2	J. D. McCrumm
Syracuse Univ., Syracuse, N. Y	1	C. W. Henderson
Tennessee, Univ. of, Knoxville	4	J. G. Tarboux
Texas A. & M. Col., College Station	7	N. F. Rode
Texas Technological Col., Lubbock	7	W. F. Helwig
Texas, Univ. of, Austin	7	R. A. Galbraith
Tufts Col., Tufts College, Mass	1	E. A. Walker
Tulane Univ., New Orleans, La	4	C. B. Norris
Union Col., Schenectady, N. Y	1	J. E. Paul
Utah, Univ. of, Salt Lake City	9	P. L. Poole
Vermont, Univ. of, Burlington	1	B. R. McKee
Villanova Col., Villanova, Pa	2	H. S. Bueche
Virginia Military Inst., Lexington	4	J. S. Jamison
Virginia Polytechnic Inst., Blacksburg	4	Claudius Lee
Virginia, Univ. of, University	4	L. R. Quarles
Washington, State Col. of, Pullman	9	H. P. Lickey
Washington, Univ. of, Seattle	9	R. E. Lindblom
Washington Univ., St. Louis, Mo	7	H. G. Hake
West Virginia Univ., Morgantown	3	A. H. Forman
Wisconsin, Univ. of, Madison	5	R. R. Benedict
Worcester Polytechnic Inst., Worcester, Mass	1	V. Siegfried
Wyoming, Univ. of, Laramie	6	G. H. Sechrist
Yale Univ., New Haven, Conn	1	A. G. Conrad

Total.....122

Local Sections of the Institute

Name	District	When Organized	Membership Aug. 1, 1940	Chairman	Secretary	Secretary's Address
Akron	2	Aug. 12, '20	85	F. A. Green	H. L. Rorden	Ohio Brass Co., Barberton, Ohio
Alabama	4	May 22, '29	40	T. H. Mawson	W. W. R. Purcell	Alabama Power Co., Birmingham, Ala.
Boston	1	Feb. 13, '03	415	R. W. Adams	W. I. Middleton	Simplex Wire and Cable Co., Cambridge, Mass.
Central Indiana	5	Jan. 12, '12	132	R. A. Scholl	B. T. Loeffler	Indiana Bell Telphone Co., Indianapolis, Ind.
Chicago	5	1893	769	F. V. Smith	K. V. Glentzer	Illinois Bell Telephone Co., Chicago, Ill.
Cincinnati	2	June 30, '20	207	C. F. Lee	H. E. Barnett	Cincinnati and Suburban Bell Telephone Co., Cincinnati, Ohio
Cleveland	2	Sept. 27, '07	332	L. C. Porter	Wm. R. Hough	Reliance Electrical and Engineering Co., Cleveland, Ohio
Columbus	2	Mar. 17, '22	93	F. A. Teach	D. B. Stafford	National Electric Coil Co., Columbus, Ohio
Connecticut	1	Apr. 16, '21	279	T. J. Russell	A. G. Conrad	Yale University, New Haven, Conn.
Denver	6	May 18, '15	192	W. G. Rubel	J. R. Walker	U. S. Bureau of Reclamation, Denver, Colo.
East Tennessee	4	Sept. 2, '36	132	J. G. Tarboux	J. D. Harper	Aluminum Company of America, Alcoa, Tenn.
El Paso	7	Mar. 7, '40	47	I. W. Best	F. A. Decker	College of Mines and Metallurgy, El Paso, Texas
Erie	2	Jan. 11, '18	57	J. D. Heibel	W. D. Bearce	4121 Sassafras St., Erie, Pa.
Florida	4	Jan. 28, '31	78	H. J. B. Scharnberg	Joseph Weil	University of Florida, Gainesville, Fla.
Fort Wayne	5	Aug. 14, '08	109	Wayne Kehoe	G. C. Harvey	General Electric Co., Fort Wayne, Ind.
Georgia	4	Jan. 14, '04	109	E. H. Bailey	J. M. Flanigen	Georgia Power Co., Atlanta, Ga.
Houston	7	Aug. 7, '28	141	L. H. Matthes	P. H. Underwood	P. O. Box 1700, Houston, Tex.
Iowa	5	June 25, '29	72	H. H. Brown	G. R. Corcoran	State University of Iowa, Iowa City, Iowa.
Ithaca	1	Oct. 15, '02	51	M. G. Northrop	John P. Wood	Cornell University, Ithaca, N. Y.
Kansas City	7	Apr. 14, '16	148	P. C. Ellis	G. K. Shirling	Southwestern Bell Telephone Co., Kansas City, Mo.
Lehigh Valley	2	Apr. 16, '21	191	W. J. D. Geary	J. E. Treweek	Pennsylvania Power and Light Co., Hazleton, Pa.
Los Angeles	8	May 19, '08	506	J. M. Gaylord	T. M. Blakeslee	Bureau of Power and Light, Los Angeles, Calif.
Louisville	4	Oct. 15, '26	61	J. F. Miller	J. R. Smith	Louisville Gas and Electric Co., Louisville, Ky.
Lynn	1	Aug. 22, '11	147	L. P. Shildneck	J. H. Goss	General Electric Co., Bldg. 2-M., Lynn, Mass.
Madison	5	Jan. 8, '09	67	H. J. Kubiak	F. A. Maxfield	University of Wisconsin, Madison, Wis.
Mansfield	2	Mar. 6, '39	68	W. B. Johnson	H. O. Whitely	North Electric Manufacturing Co., Galion, Ohio
Maryland	2	Dec. 16, '04	252	C. S. Fiske	H. J. Casey	Baltimore Transit Co., Baltimore, Md.
Memphis	4	May 23, '30	72	E. J. Biegel	W. M. Brewer, Jr.	Memphis Light, Gas and Water Division, Memphis, Tenn.
Mexico	8	June 29, '22	56	C. Santacruz	C. C. Jagou	Apartado 2966, Mexico City, Mexico
Michigan	5	Jan. 13, '11	376	E. V. Sayles	S. M. Dean	Detroit Edison Co., Detroit, Mich.
Milwaukee	5	Feb. 11, '10	280	R. R. Ranson	G. W. Clothier	Allis-Chalmers Manufacturing Co., Milwaukee, Wis.
Minnesota	5	Apr. 7, '02	107	R. E. Burlingame	H. E. Hartig	University of Minnesota, Minneapolis, Minn.
Montana	9	June 24, '31	36	E. W. Schilling	Herold Murdock	The Montana Power Co., Bozeman, Mont.
Muscle Shoals	4	Feb. 18, '38	33	B. M. Anthony	J. P. Hamilton	Box 783, East Florence, Ala.
Nebraska	6	Jan. 21, '25	48	L. A. Bingham	John M. Gibb	504 City Hall, Omaha, Nebr.
New Orleans	4	Dec. 8, '33	123	E. B. Mabson	F. E. Johnson	317 Baronne St., New Orleans, La.
New York	3	Dec. 10, '19	3,346	J. F. Fairman	C. C. Whipple	Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.
Niagara Frontier	1	Feb. 10, '25	197	G. W. Eighmy	Wm. K. Parks	Westinghouse Electric and Manufacturing Co., Buffalo, N. Y.
North Carolina	4	Mar. 21, '29	91	Albert Milmow	G. O. Bason	107 Latta Arcade, Charlotte, N. C.
North Texas	7	May 18, '28	170	H. R. Pearson	G. N. Pingree	General Electric Co., Dallas, Tex.
Oklahoma City	7	Feb. 16, '22	117	W. B. Stephenson	John Shawver	Oklahoma Gas and Electric Co., Oklahoma City, Okla.
Philadelphia	2	Feb. 18, '03	650	D. C. Prince	W. B. Morton	Philadelphia Electric Co., Philadelphia, Pa.
Pittsburgh	2	Oct. 13, '02	564	G. R. Patterson	R. L. Dunlap	Bell Telephone Co. of Pa., Pittsburgh, Pa.
Pittsfield	1	Mar. 25, '04	192	E. V. DeBlieux	M. E. Scoville	General Electric Co., Pittsfield, Mass.
Portland	9	May 18, '09	176	J. A. Hooper	D. L. Brown	Portland General Electric Co., Portland, Ore.
Providence	1	Mar. 12, '20	99	H. A. Baines	O. B. Sawyer	56 Friendly Road, Auburn, R. I.
Rochester	1	Oct. 9, '14	103	Wm. F. Cotter	C. F. Harris	Westinghouse Electric and Manufacturing Co., Rochester, N. Y.
St. Louis	7	Jan. 14, '03	273	L. L. Crump	J. S. Malsbary	Wagner Electric Co., St. Louis, Mo.
San Antonio	7	May 23, '30	45	N. B. Gussett	W. F. Pinckert	203 Elmhurst St., San Antonio, Tex.
San Diego	8	Jan. 18, '39	36	W. L. Bryant, Jr.	B. B. Gravitt	General Electric Co., San Diego, Calif.
San Francisco	8	Dec. 23, '04	507	C. V. Fowler	B. L. Robertson	University of California, Berkeley, Calif.
Saskatchewan	10	Oct. 14, '25	15	B. J. O. Strong	W. E. Bolton	2339 Garnet St., Regina, Sask., Can.
Schenectady	1	Jan. 26, '03	434	E. M. Hunter	T. T. Woodson	General Electric Co., Research Laboratory, Schenectady, N. Y.
Seattle	9	Jan. 19, '04	164	G. R. Shuck	C. H. Cutter	Pacific Electric Manufacturing Co., Seattle, Wash.
Sharon	2	Dec. 11, '25	105	C. L. Knotts	H. R. Arnold	Westinghouse Electric and Manufacturing Co., Sharon, Pa.
South Carolina	4	Mar. 2, '40	37	T. F. Ball	S. R. Rhodes	Clemson College, Clemson, S. C.
Spokane	9	Feb. 14, '13	81	H. B. Hodgins	H. J. Reeves	North 3627 Audubon St., Spokane, Wash.
Springfield	1	June 29, '22	57	H. D. Griffith	Isaiah Creaser	76 Cortland St., Springfield, Mass.
Syracuse	1	Aug. 12, '20	75	E. A. Gruppe	V. J. Brown	157 Shotwell Park, Syracuse, N. Y.
Toledo	2	June 3, '07	71	H. R. Daykin	W. M. Campbell	2145 Central Grove Ave., Toledo, Ohio
Toronto	10	Sept. 30, '03	342	J. M. Thomson	F. C. Barnes	Canadian General Electric Co., Ltd., Toronto, Ont., Can.
Tulsa	7	Oct. 1, '37	94	H. P. Dougherty	J. V. McGinity	American Steel and Wire Co., Tulsa, Okla.
Urbana	5	Nov. 25, '02	76	H. H. Horn	L. B. Archer	University of Illinois, Urbana, Ill.
Utah	9	Mar. 9, '17	76	O. C. Haycock	J. A. McDonald	General Electric Co., 200 S. Main St., Salt Lake City, Utah.
Vancouver	10	Aug. 22, '11	97	J. H. Steede	B. O. Lunn	150 Cordova St., Vancouver, B. C., Can.
Virginia	4	May 19, '22	111	C. L. Crosby	Llewellyn Saunders	1042 Jamestown Crescent, Norfolk, Va.
Washington	2	Apr. 9, '03	370	J. E. O'Brien	W. J. Ellenberger	Potomac Electric Power Co., Washington, D. C.
West Virginia	4	Apr. 9, '40	48	E. B. Snyder	D. L. Gunter	Appalachian Electric Power Co., Charleston, W. Va.
Wichita	7	Sept. 16, '37	52	P. S. Colby	R. B. Gow	Kansas Gas & Electric Co., Wichita, Kans.
Worcester	1	Feb. 18, '20	63	A. H. Magnuson	W. W. Locke, Jr.	Worcester Polytechnic Institute, Worcester, Mass.
Total	70					

Of Current Interest

Foster Parents Needed for Child Refugees

The following message is addressed to AIEE members by Marshall Field, president of the United States Committee for the Care of European Children, Inc.

With the increasing seriousness of the situation in Great Britain, steps for the evacuation of children to the United States are taking concrete form. The British Government, forced to postpone its own evacuation plans because of the critical need for its naval strength at home, has 200,000 children voluntarily registered for departure overseas. Of this number it is hoped that about 50,000 will come to the United States, and immigration visas for some 3,000 have already been cleared with the Department of State.

Responsible for America's hospitality to these children is the United States Committee for the Care of European Children. This is the organization officially recognized by the United States Government and British authorities as the agency co-ordinating the efforts of all social-welfare groups in this country prepared to aid in the task. Its function is to clear the paths for the admission here of as many refugee children as possible and to see that they are adequately provided for. Transportation facilities on the other side are being arranged by a co-operating group, the American Committee for the Evacuation of British Children, organized under the sponsorship of United States Ambassador Joseph J. Kennedy.

The most pressing need in the United States, in addition to that for funds, is for foster homes. Thus far, some 7,000 American families have opened their doors. Prospective foster parents offering full support are required by government regulation to submit an affidavit, which varies in detail. The foster parent must guarantee that the child will not become a public charge, that his care will at all times be in accordance with the standards of the Children's Bureau of the Department of Labor and subject to supervision by a local child-care agency designated by the United States Committee. Income must be stipulated; a credit investigation will be made and evidence requested to support the affidavit. However, individuals will be spared the considerable trouble which attends immigration, for the United States Government has agreed to accept the corporate affidavit of the United States Committee, based on the collective assurances of individuals, guaranteeing the proper care of the children while they are here and setting aside the sum of $50 for each child as a trust fund to be held as a safeguard against future contingencies.

The children coming here will all be under 16, from all types of homes representing all religions and backgrounds. Where conditions permit, French, Polish, Dutch, Belgian, and other children will be included. Their stay is limited to two years and each child must have a home abroad to which he can return at the end of the war. Of those now expected here, none will have friends or relatives in this country. British children may not be legally adopted in the United States as that is contrary to British law. If the child should lose his father and mother in the war, the American foster parents will have no added responsibility.

All children will be given medical examinations both on the other side and here. They will be expected to attend school until they are 16. About 150 private schools have volunteered to maintain groups of boys or girls free or at reduced tuition.

Funds are needed at once for the support of children for whom suitable foster homes are available but in families unable to afford the expense; and for the shelter and care of arriving children pending their placement. The United States Committee has launched a national campaign for $5,000,000 to carry on its job.

Members of the AIEE are invited to lend their homes for the duration either for full or partial support of one or more children. More complete details may be obtained from the United States Committee for the Care of European Children, 215 Fourth Avenue, New York, N. Y.

From AEC . .

ITEMS appearing under this heading are from the news service of American Engineering Council.

New Executive Secretary Appointed

Colonel L. B. Lent, well known as an engineer, inventor, and trade association executive, has been appointed executive secretary of AEC, succeeding Frederick M. Feiker (M'34) who resigned several months ago to become dean of engineering at George Washington University. Colonel Lent is a native of Brewster, N. Y., and a graduate of Stevens Institute of Technology, Hoboken, N. J. After five years as associate editor of *Power* his studies of gas-engine development led to an association with the Riverside Engine Company, Oil City, Pa. The installation by this firm of several large engines for the Ford Motor Company resulted in his employment by that company as assistant chief engineer of construction and maintenance.

As an inventor, Colonel Lent secured patents on a motor pumper type of fire engine and founded a company to manufacture these units. The World War, however, abruptly terminated this activity. Entering the Army, he was assigned to the development of airplane engines at the Curtiss plant in Buffalo, N. Y., subsequently being transferred to Langley Field, Va., as engineer officer, and later to Camp Vail, N. J., as commanding officer of Air Service troops at that field. Later, he had command at Brindley Field and Roosevelt Field.

After the war he became superintendent of the United States Air Mail Service and played a prominent part in the development of the early routes connecting Chicago with St. Louis, Minneapolis, and San Francisco and organized the first transcontinental service from New York to San Francisco.

Colonel Lent entered trade association work as chief engineer of the Common Brick Manufacturers' Association of America. He later became executive officer of the Scientific Apparatus Makers Association, writing and administering the NRA code for the 500 members of this industry. He was then made president of the Panoptik Company, which administered a patent licensing plan in the field of optical products. More recently he has been a consultant in the aviation field, especially as engineer to the Aeronautical Development Commission of the State of Connecticut.

Goals in National Defense

Approval by Congress of an expanded United States Navy exceeding in size the combined present fleets of Great Britain and Japan, announcement of the financing of a new plant that will double present production of high-power aviation engines, and assurances from William S. Knudsen of the National Defense Advisory Commission that the United States has the industrial ability to equip a force of 2,000,000 fighting men, were high spots of an eventful month in Washington.

The rapidity with which the armament program is being accelerated may be gauged from Mr. Knudsen's report that between June 6 and July 25 contracts were cleared aggregating $1,412,807,678 for the Navy and an additional $315,288,152 for the Army. As pointed out by Mr. Knudsen, *contract awards are far removed from finished goods*, and there are many problems of production still to be solved.

Few persons realize the complexity of the task of supplying a modern army and navy. Unofficial estimates place the number of needed articles at 70,000, of which all but some 3,700 are commercially manufactured. Most of these latter can be manufactured in existing plants at the cost of some disturbance to normal operations, and it is this type of article that has been the subject of recent "educational orders" placed to accustom selected manufacturers to quantity production when this becomes necessary. During recent years the War Department has inspected 20,000 commercial plants to procure definite knowledge of their equipment and capacity, and has assigned

definite products to 10,340 of these. There still remain, however, some 200 critical items requiring highly specialized equipment or methods not applicable to peacetime uses, and these must be produced in Government-owned plants. Thus the Army's plans for a major military emergency include the erection of 78 ordnance, 28 chemical, and 2 quartermaster plants at a total cost of more than $600,000,000. Congress already has earmarked approximately this amount for such construction. (W. H. Harrison, AIEE past-president, recently was appointed to serve as the Commission's director of new plant construction.)

Aside from the building of this type of plant, there is sure to be considerable expansion of private facilities, particularly in the aviation industry. Not only is the United States determined to build up its own air forces, but the British have announced their desire to buy planes at the rate of 3,000 per month for the next two years, and their willingness to finance the plant expansion necessary to attain this goal. The first defense-plant construction loan to be approved by the Reconstruction Finance Corporation was for a $92,000,000 plant for the Wright Aeronautical Corporation to be located near Cincinnati, Ohio. This will turn out 12,000 airplane motors annually, virtually doubling present American production capacity.

ADVISORY COMMITTEES NAMED

To avoid overloading the construction industry in any one locality and to provide general co-ordination and advice on plant and construction problems, the Army and Navy Munitions board has appointed a civilian committee of construction experts with the following members:

Colonel John P. Hogan, president, American Society of Civil Engineers, *chairman*; Alonzo J. Hammond, president, American Engineering Council; E. J. Harding, general manager, Associated General Contractors of America; E. P. Palmer, past president of the Associated General Contractors; Malcolm Pirnie, chairman of the Construction League; Stephen F. Voorhees, past president of the American Institute of Architects.

A second committee of civilian experts has been named by the War Department to speed up the negotiation of construction contracts. This advisory section will recommend, for each building job, three firms which appear best qualified to perform the work; the Department then will attempt to negotiate a contract with one of these on a cost-plus-fixed-fee basis. Appointments to the committee so far are: Francis Blossom, of Sanderson and Porter, New York; Forrest S. Harvey, recently with Lee, Hill, Barnard, and Jowett, Los Angeles; and F. J. C. Dresser, Cleveland, director of the American Construction Council. Two other members are yet to be named.

TVA EXPANDED

At the request of the Defense Commission, Congress has appropriated $25,000,000 to begin a $65,000,000 expansion program by the Tennessee Valley Authority which will provide additional power facilities "for the production of aluminum and other defense materials in its territory." Included will be a new dam on the Holston River, an auxiliary steam generating station, and additional hydroelectric generating units at Wilson and Pickwick Landing Dams.

TAX-REVISION BARRIER CAUSES DELAY

Expansion of privately owned plants currently is being delayed by pending revisions of the tax laws. The Defense Commission long ago pointed out that manufacturers could not be expected to invest large sums in new plant and equipment that might be rendered unusable by the negotiation of an unexpected peace, and suggested that one acceptable way of cushioning this risk would be to permit the new facilities to be amortized in five years instead of ten. This change in income tax practice could be effected by a simple amendment by Congress, and this procedure is recommended. Congressional leaders, however, insisted upon the political advisability of considering this change together with pending legislation imposing excess profits taxes and revising the restrictions on profits from shipbuilding and aircraft contracts, with the result that the plant construction program is in suspense until this complicated situation can be debated and disposed of.

NAVY INCREASED 70 PER CENT

In authorizing an unprecedented increase in the size of the Navy, Congress embarked upon a construction program that will mean the annual expenditure of $2,000,000,000 for construction until 1947. How this will expand the fleet is indicated in the following table:

Category	Now in Service	Now Under Construction	Ultimate Strength
Battleships	15	10	35
Airplane carriers	6	5	20
Cruisers	37	21	88
Destroyers	236	61	378
Submarines	101	41	180
Total	395	138	701

To meet this heavy construction schedule considerable expansion in shipbuilding facilities will be required, and $150,000,000 is authorized for this purpose.

Migrant Labor Problems

Economic and social questions arising from maladjustments between the supply of and demand for migratory labor are currently being studied by a Congressional committee which, during the next four months, will hold hearings and view conditions in all parts of the United States, with the purpose of recommending remedial legislation to the next Congress.

The magnitude of this question is pointed out by a recent report made to the President by an interdepartmental committee to co-ordinate health and welfare activities of the Federal Government. It estimates that there are now 2,000,000 persons without fixed habitations looking to agriculture for a living, and at least an equal number dependent upon industry. More than half of the 48 states are directly affected. Remedial steps recommended include:

1. Federal-state co-operation to accelerate the collection and study of information, and to promote public understanding of the problem.
2. Federal aid for educational, recreational, and welfare services in communities affected.
3. More Federal camps for migratory agricultural labor.
4. A Federal-state program to provide them with health and medical services.
5. Closer Federal regulation of labor-recruiting activities and the extension of wage-hour and social-security benefits to migrants.

Havana Parley

Co-operation among the 21 republics of the western hemisphere, which has been increasing steadily since the outbreak of war in Europe, attained new heights as the result of a successful conference on economic and military problems held in Havana late in July. The discussions centered around three principal problems, all closely related to the war. Decisions were reached as follows:

1. Supporting recent United States affirmations regarding the Monroe Doctrine, it was decided that rather than to permit the exchange of colonies in the western hemisphere from one European nation to another, such territory will be taken over and governed temporarily by a joint committee representing all American nations, and eventually either given an independent status or returned to its original jurisdiction. In an emergency it becomes "the right and duty" of any one or more signatories to take action to prevent any such transfer. In effect, this means general acceptance of the Monroe Doctrine and the granting of blanket permission to the United States to enforce it without incurring the old charge of "imperialism."
2. All signatories agreed freely to exchange information on propaganda or "fifth column" activities and to develop standards defining the legitimate activities of diplomatic and consular officials.
3. To meet current disruption of international trade and possible future attempts to use it as a method of political warfare, it was agreed to strengthen and expand present facilities for stimulating inter-American trade and increasing consumption within the hemisphere in all possible ways.

Pan-American Relations

Responding to an invitation by the Department of State, Colonel L. B. Lent, new executive secretary of American Engineering Council, and C. O. Bickelhaupt (M'22, F'28), chairman of its committee on inter-American engineering relations, conferred August 1 with C. A. Thomson, H. H. Pierson, and Richard Pattee, of the Division of Cultural Relations, relative to specific methods by which the committee can lend its advice and assistance to the State Department. The discussion centered about facilities for the introduction to the profession of engineers arriving from abroad, specifically the eight Latin-American students soon to arrive in this country to attend the Farm Equipment Seminar, as well as others expected to come later under the exchange plan now being inaugurated. The committee also was asked to consider the problem of securing applications from qualified engineering teachers for exchange professorships under this same plan, for which funds are now available.

The State Department has asked Council to broadcast the information that many requests are being received from abroad for informative educational motion picture films reflecting the life, ideals, and customs of the United States. While a certain number of government films are available, the

Department could meet these requests more adequately if it had available for distribution films of this type produced by other than government agencies, and it is hoped that these will be made available by those who have them.

Plan Board Surveys U. S.

Facts and figures regarding many factors entering into the trend of American life are gathered together in a recent report of the National Resources Planning Board. Topics considered include population trends and their effects, national income, transportation, agriculture, national resources, education, and public works. Some of the conclusions reached are:

1. U. S. population will increase to 158,000,000 by 1980, thereafter remain stationary or decline. Between 1935 and 1975 the number of persons aged 20 to 44 will increase by only 6 per cent, while those in the age group 45 to 64 will increase 69 per cent. Enrollment in schools and colleges will increase for several years, then level off.

2. Planning on a national scale is necessary to make the most effective use of resources in many fields. For example, conflicts among railroads, highways, airways, waterways, and pipe lines result in unnecessary duplications of service and high costs to the general public.

3. Research activities of various government agencies should be co-ordinated to avoid confusion and undue expense.

4. To provide medical service to the one-third of the population that is classed in the lowest income bracket (under $750 per year) would cost $850,000,000 annually. Economic losses attributable to illness and premature death are estimated now at 10 billion dollars annually.

PWA Starts Liquidation

After seven years of operation in the financing and supervision of construction projects in all parts of the country, the Public Works Administration is now engaged in winding up its affairs under the Congressional mandate that it be completely liquidated by July 1, 1941. Personnel, which reached a peak of 10,400 persons when the last (1938) program was in full swing, is now down to 2,331, including over 500 engineers, and further reductions are being made rapidly.

Portable Generators for REA Projects

Diesel-electric generating station units mounted on trailers will be used to supply power for at least three rural electric systems financed through the Rural Electrification Administration, according to a recent announcement. Two such units are now going into service for the Jo-Carroll Electric Cooperative, an Illinois organization supplying 600 families through 278 miles of line, and the purchase of similar units has been authorized for two other REA projects in Oregon.

One of the latter projects centers about the town of Jordan Valley, located 25 miles from the nearest available source of electricity. The other two projects have been unable to buy power at low rates and are therefore resorting to this method of supplying power during the initial load-building period, with the idea of making more permanent arrangements after their loads become stabilized.

Each portable unit consists of two Diesel-powered generators of 60- and 40-kw capacity, respectively, mounted upon a rubber-tired trailer. No building is required to house them and they may be connected to the power line at any convenient point through step-up transformers. Operation is semiautomatic, requiring only the part-time attention of one man.

Industry • • • •

Electrical Engineering Exposition to Be Held in Philadelphia

An Electrical Engineering Exposition will be held in Convention Hall, Philadelphia, Pa., January 27–31, 1941, during the same week as the AIEE winter convention, which also takes place in Philadelphia. The Exposition, said to be the first of its kind ever held, is designed to serve the electrical industry by promoting a more rapid dissemination of information on new developments in electrical engineering. Exhibits will include new and improved electrical products for the generation, transmission, and utilization of electric energy.

Members of the advisory committee of the exposition are:

J. T. Barron (A'07, F'27) vice-president, Public Service Electric and Gas Company, Newark, N. J.; Walter S. Finlay, Jr. (A'18, F'21) vice-president, J. G. White, Engineering Corporation, New York, N. Y.; E. S. Fitz (A'16, M'32) general manager, electrical department, Virginia Electric and Power Company, Richmond; N. E. Funk (A'07, F'34) vice-president, Philadelphia (Pa.) Electric Company (chairman, AIEE 1941 winter convention committee); C. W. Leihy (A'30, M'38) editor, *Electric Light and Power*, Electrical Publications, Inc., Chicago, Ill.; A. L. Pennimann, Jr. (A'15, M'32) general superintendent, electric operations, Consolidated Gas, Electric Light and Power Company of Baltimore, Md.; W. A. Perry (M'38) superintendent, electric and power departments, Inland Steel Company, East Chicago, Ind.; R. C. Roe (A'18, F'33) president, Burns and Roe, Inc., New York, N. Y.; Charles F. Roth, manager, exposition; B. K. Stevens, manager, exposition; R. W. Wilbraham (M'21) chief electrical engineer, United Engineers and Constructors, Inc., Philadelphia, Pa.; S. B. Williams (M'37) editor, *Electrical World*, McGraw-Hill Publishing Company, New York, N. Y.

The exposition is being sponsored by International Exposition Company, Grand Central Palace, New York, N. Y., which also conducts the National Power Show, the Exposition of Chemical Industries, and the International Heating and Ventilating Exposition.

Transmitting Station. A new 50,000-watt air-cooled transmitting station for Westinghouse radiobroadcasting station WBZ, Boston, Mass., recently was put into operation at Hull, Mass., across the harbor from Boston. Although the new transmitter has the same power output as the former one, the use of a directive antenna is expected greatly to extend its range. The transmitting station was opened with network ceremonies that included the splitting of an atom of uranium, by means of which power was switched to the new station.

Fluorescent Lighting for Offices

One of the most comprehensive commercial installations yet made of fluorescent lighting is being tried in a large Philadelphia building. The try-out is of interest not only to illuminating engineers, but also to office-building managers, because it represents the first attempt to make this type of lighting a major attraction in leasing office space.

The experiment is being carried out in the Broad Street Station Building of the Pennsylvania Railroad, where five offices on the tenth floor—two of them presenting unusual problems because they are inside rooms without windows—have been provided with the new lighting, installed in each case in ceiling fixtures. A different type of installation has been used in each of the five rooms, developed to produce substantially uniform lighting intensity of 20 foot-candles or more at the working plane. The two inside rooms also have been equipped by the designer with "illusion" windows, having Venetian blinds and draperies so arranged that concealed fluorescent tubes along the sides create the appearance of subdued sunlight streaming in behind the curtain.

Utility to Use "FM." Frequency-modulation radio communication is being used for an emergency communications system being installed by Indianapolis Power Company, Indianapolis, Ind. The company is equipping ten service cars and trucks with 25-watt mobile transmitters and receivers for two-way communication, enabling the vehicles to be in constant contact with main headquarters, where a 250-watt station transmitter will be in operation. The 25-watt frequency-modulated transmitters are expected to give service over a greater area than was reached by the best of previous 250-watt amplitude-modulated transmitters.

New Generating Station. Consumers Power Company's new steam power plant, the John C. Weadock Station, Bay City, Mich., which was dedicated June 20, 1940, has a capacity of 35,000 kw, furnished by the first of two hydrogen-cooled turbine generators. Furnace and boiler for the second unit, which will bring the capacity to 70,000 kw, have been built into the plant. The unit now in operation is a 21-stage tandem-compound turbine designed for a steam pressure of 800 pounds per square inch and a steam temperature of 850 degrees Fahrenheit, and operating at 3,600 rpm.

Synthetic Rubber. Formation of the Hydrocarbon Chemical and Rubber Company for the production of synthetic rubber was recently announced by the B. F. Goodrich Company and the Phillips Petroleum Company. "The close co-ordination between the two companies will hasten the day when, if necessary, every American tire, as well as the thousands of other rubber products, can be made wholly with American rubber," a joint statement declared.

"Telephone of Tomorrow." Demonstration of an operating unit combining telephone and television equipment is part of

the "previews of progress" shown this year in the General Motors exhibit at the New York World's Fair. The apparatus consists of a standard portable television transmitter connected by co-axial cable with a 12-inch-screen experimental television receiver. A push-button telephone is coordinated with the television circuit so that when the telephone instrument is lifted at the receiving end, the image of the person answering flashes on the screen.

Other Societies •

Engineering Jobs Abundant in Detroit

Many engineering positions reported to the Detroit office of the Engineering Societies Personnel Service, Inc., since its opening July 1, are unfilled because of lack of registrants, the Service reports. Engineering societies participating in the Service are being asked to call this fact to the attention of their members in the Detroit area, so that those who are unemployed or wish to change to a better position may register immediately in person or by mail. It is expected that a great many more positions in all fields of engineering will become available in September with the start of production on the 1941 automobiles and on government contracts for national-defense material.

SPEE Surveys Undergraduate Promise

Among papers presented at the annual convention of the Society for the Promotion of Engineering Education at the University of California, June 24–28, 1940, were three reports of the co-ordinated committees on personal development. These were "What Industry Considers Promising Material," "Exploring Promise in the Undergraduate," and "Discovery of Promising Freshman Engineers."

The first report, by the committee headed by Professor John R. Bangs, Cornell University, stressed particularly the growing sensitivity of industry to the necessity of character and proper personality in addition to scholastic and academic advancement. The report placed a considerably responsibility on the engineering colleges for the development of character and desirable personal qualities.

The second report, by Doctor Edward K. Strong, Jr., Stanford University, stressed some of the possibilities of discovering and exploring promising human material, from which to develop engineers. The report indicated that every means at present known to modern science, particularly psychology and statistics, is being used to select students and guide them in the choice of a profession or life work.

The last report, of the committee headed by Doctor R. L. Sackett, showed the participation of engineers in high-school counseling of those boys who want to know what engineering is and pointed out the higher standards for admission to engineering schools as compared with practice ten years ago. Sentiment toward seeking an inventory of student personality and character, rather than scholarship only, in selecting those admitted, is seen to be growing, though only in embryo at present. A larger variety of tests is being used as an aid in selection of students or in the guidance of those who are not progressing satisfactorily. The percentage dropped because of poor performance in engineering education is decreasing as a result of better guidance and selection. As a result, the percentage of graduates shows signs of increasing.

Future Meetings of Other Societies

American Gas Association. October 7–10, 1940, Atlantic City, N. J.

American Institute of Mining and Metallurgical Engineers. Joint meeting, AIME Coal Division, ASME Fuels Division, November 7–9, 1940, Birmingham, Ala.

American Institute of Physics. Conference on applied nuclear physics, with Massachusetts Institute of Technology, October 28–November 2, 1940, Cambridge, Mass.

American Physical Society. 237th meeting, November 22–23, 1940, Chicago, Ill.

238th meeting, December 1940, Pasadena, Calif.

239th meeting (annual meeting), December 26–28, 1940, Philadelphia, Pa.

American Society of Civil Engineers. Fall meeting, October 16–18, 1940, Cincinnati, Ohio.

American Society of Heating and Ventilating Engineers. Fall meeting, October 14–15, 1940, Houston, Tex.

American Society of Mechanical Engineers. Fall meeting, September 3–6, 1940, Spokane, Wash.

Annual meeting, December 2–3, 1940, New York, N. Y.

American Transit Association. 59th annual convention, September 23–26, 1940, White Sulphur Springs, W. Va.

American Welding Society. Annual meeting, October 20–25, 1940, Cleveland, Ohio.

Association of Iron and Steel Engineers. Annual convention, September 24–27, 1940, Chicago, Ill.

Conference on Electrical Insulation (National Research Council). October 31–November 2, 1940, Washington, D. C.

Electrochemical Society. Fall meeting, October 2–5, 1940, Ottawa, Canada.

Engineers' Council for Professional Development. Annual meeting, October 24, 1940, Pittsburgh, Pa.

National Electrical Contractors Association. Fall meeting, October 21–23, 1940, Jacksonville, Fla.

National Electrical Manufacturers Association. Annual meeting, October 27–November 1, 1940, New York, N. Y.

American Society for Metals. National Metal Congress. October 20–25, 1940, Cleveland, Ohio.

National Safety Council. October 7–11, 1940, Chicago, Ill.

Society of Automotive Engineers. National aircraft production meeting, October 31–November 2, 1940, Los Angeles, Calif.

Letters to the Editor • • •

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A Transformation Extending the Use of Heaviside's Operational Calculus

To the Editor:

Heaviside's operational calculus is based essentially on zero initial charges and currents in the networks being studied. Such initial conditions do not permit as complete a study of transient behavior as is desirable, so considerable effort has been expended in extending the class of initial conditions which may be employed with Heaviside's calculus.

The following simple change of variable permits the use of Heaviside's expansion theorem to include all linear lumped networks with no restrictions as to initial conditions.

Let

$$\int_0^t i(\lambda)d\lambda = q(t) - q(0) \tag{1}$$

and

$$q(0) = 0 \tag{2}$$

If $i(t)$ represents a cyclic or mesh current, $q(t)$, defined by these equations, will represent the total charge which flows past a circuit point during the time interval 0 to t as a result of the current $i(t)$. The charge $q(t)$, called the mesh or cyclic charge, may or may not represent the actual charge on a capacitor in the network. This mesh or cyclic charge, according to equation 2, will always be initially zero.

Next let $q'(t)$ be defined by

$$q(t) = q'(t) + t \cdot i(0) \tag{3}$$

and note that

$$q'(0) = 0 \tag{4}$$

because of equations 2 and 3. This charge $q'(t)$ may have little, if any, physical significance. Now let a second change of variable be made according to

$$i'(t) = \frac{d}{dt} q'(t) = p \cdot q'(t) \tag{5}$$

Substituting for equation 3, this equation is

$$i'(t) = p \cdot q(t) - i(0) = i(t) - i(0) \tag{6}$$

Therefore,

$$i'(0) = 0 \tag{7}$$

That is, the initial value of $i'(t)$ is zero, no matter what the initial value of $i(t)$.

Therefore, if the equations of a network are expressed in terms of $i'(t)$ and $q'(t)$, the initial conditions will always be zero, and Heaviside's expansion theorem applies. Once $i'(t)$ or $q'(t)$ are determined, $i(t)$ and $q(t)$ may be established from the foregoing equations.

The following example will show the method of employing the change of variable defined in the preceding to solve a network problem. The network shown in figure 1 will be considered.

The voltage equations for this circuit in terms of mesh and capacitor charges are (switch in b position)

$$E = (Lp^2+Rp)\cdot q_1(t) - Lp^2\cdot q_2(t) \tag{8}$$

$$O = -Lp^2\cdot q_1(t) + Lp^2\cdot q_2(t) + \frac{1}{C}q_{2s}(t) \tag{9}$$

Since from the definition of mesh charges, the charge on any capacitor is the algebraic sum of all the mesh charges associated with the branch of the capacitor and the initial charge on the capacitor

$$q_{2s}(t) = q_2(t) + q_0 \tag{10}$$

and since for a V_c (the initial voltage drop of the capacitor) assumed direction as shown in figure 1,

$$V_c = -\frac{1}{C}q_0 \tag{11}$$

equations 8 and 9 can be written

$$E = (Lp^2+Rp)\cdot q_1(t) - Lp^2\cdot q_2(t) \tag{12}$$

$$V_c = -Lp^2\cdot q_1(t) + \left(Lp^2+\frac{1}{C}\right)\cdot q_2(t) \tag{13}$$

Next, making the substitution of equation 3, these equations become

$$E - Ri_1(0) = (Lp^2+Rp)\cdot q_1'(t) - Lp^2\cdot q_2'(t) \tag{14}$$

$$V_c - \frac{i_2(0)}{C}\frac{1}{p} = -Lp^2\cdot q_1'(t) + \left(Lp^2+\frac{1}{C}\right)\cdot q_2'(t) \tag{15}$$

Finally, since from equation 5

$$q'(t) = \frac{1}{p}\cdot i'(t)$$

these equations may be written in terms of the primed currents and the unit function as

$$[E - Ri_1(0)]1 = (Lp+R)\cdot i_1'(t) - Lp\cdot i_2'(t) \tag{16}$$

$$\frac{CV_cp - i_2(0)}{Cp}1 = -Lp\cdot i_1'(t) + \left(Lp+\frac{1}{Cp}\right)i_2'(t) \tag{17}$$

Solving these equations,

$$i_1'(t) = \frac{[E - Ri_1(0) + V_c]p^2 - \frac{1}{C}i_2(0)p + \frac{E - Ri_1(0)}{LC}}{R\left(p^2+\frac{1}{RC}p+\frac{1}{LC}\right)}1 \tag{18}$$

$$i_2'(t) = \frac{[E - Ri_1(0) + V_c]p^2 + \left[\frac{RV_c}{L} - \frac{i_2(0)}{C}\right]p - \frac{Ri_2(0)}{LC}}{R\left(p^2+\frac{1}{RC}p+\frac{1}{LC}\right)}1 \tag{19}$$

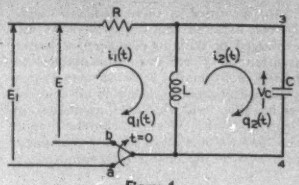

Figure 1

Employing the well-known Heaviside expansion theorem to determine the solutions for $i_1'(t)$ and $i_2'(t)$, and then using equation 6 to determine $i_1(t)$ and $i_2(t)$,

$$i_1(t) = \frac{E}{R}+\frac{1}{R}\epsilon^{-\frac{1}{2RC}t}\left\{V_c\cos\omega t + \frac{R[i_1(0)-i_2(0)]-\frac{1}{2}V_c-E}{RC\omega}\sin\omega t\right\} \tag{20}$$

$$i_2(t) = \epsilon^{-\frac{1}{2RC}t}\left\{\frac{E-R[i_1(0)-i_2(0)]+V_c}{R}\cos\omega t + \frac{R[i_1(0)-i_2(0)]+V_c\left(\frac{2R^2C}{L}-1\right)-E}{2R^2C\omega}\sin\omega t\right\} \tag{21}$$

where

$$\omega = \sqrt{\frac{1}{LC}\left(\frac{1}{2RC}\right)^2}$$

Note that for this particular network only the difference between the initial mesh currents appears. This difference is the initial current in the inductor. It should also be noted that the foregoing method takes care of the initial jump of current in this network. Correspondingly for any network, this method will automatically take care of the initial jumps of cyclic currents in the meshes containing no inductance. This, of course, is an inherent property of the Heaviside method.

The required initial values of the mesh currents must be determined beforehand by solving the network under pretransient conditions and finding the values of the currents and capacitor charges at the time of the transient's initiation.

A. J. Meyerhoff and M. B. Reed (A'36)

(Respectively graduate assistant and assistant professor, department of electrical engineering, Armour Institute of Technology, Chicago, Ill.)

Books Received

"The Norris Project". For the purpose of "giving to the engineering profession the important and useful facts about the planning and construction of the Norris dam and reservoir on the Clinch River in eastern Tennessee," a comprehensive report on planning, design, construction, and initial operations of this project, the first water-control project of the Tennessee Valley Authority, has been published, having been prepared from material compiled by the various staffs of the Authority. In addition to covering in detail the design and construction of the dam and power house, the report includes chapters on various project investigations, preliminary studies and designs, employee housing, and other related activities and studies. A separate chapter summarizes the costs of the project. The report comprises 840 pages, and is published in six- by nine-inch size with heavy cloth binding; it is profusely illustrated, including 375 illustrations and 171 tables. Copies may be procured from the Superintendent of Documents, Washington, D. C., at $1.50 each.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ELECTRICAL ENGINEERING SCIENCE. By A. Morley and E. Hughes. Longmans, Green and Company, London, New York and Toronto, 1940. 256 pages, diagrams, etc., 7½ by 5 inches, cloth, $1.75. Discusses the principles underlying the action of electrical apparatus and machines. Deals with both d-c and a-c machinery and includes chapters on transformers, electrical measurements, accumulators, and the electromagnetic system of units. Practical problems.

ELEMENTS OF ACOUSTICAL ENGINEERING. By H. F. Olson. D. Van Nostrand Company, New York, 1940. 344 pages, illustrated, 9 by 6 inches, cloth, $6.00. An exposition of the fundamental principles used in modern acoustics as applied to communication, sound reproduction, and architecture, with a description of existing acoustical instruments. Develops analogies between electrical, mechanical, and acoustical systems. Measurements and testing procedures are discussed and a chapter is devoted to speech, music, and hearing.

ELEMENTS OF ELECTROMAGNETIC THEORY. By A. W. Duff and S. J. Plimpton. Blakiston Company, Philadelphia, 1940. 173 pages, diagrams, etc., 9 by 6 inches, cloth, $2.75. Outline of the elements of the mathematical theory of electricity and magnetism, based upon a course for undergraduates at Worcester Polytechnic Institute. Topics requiring advanced mathematical knowledge have been omitted.

MATHEMATICS APPLIED TO ELECTRICAL ENGINEERING. By A. G. Warren, with a foreword by A. Russell. D. Van Nostrand Company, New York, 1940. 384 pages, diagrams, etc., 9 by 5½ inches, cloth, $4.50. Presents the mathematical methods of most fundamental value to the electrical engineer. Differential and integral calculus are dealt with most fully, with attention also given to Bessel functions, harmonic analysis, Heaviside's operational calculus, and conjugate functions. Problems.

AMERICAN SOCIETY FOR TESTING MATERIALS, PROCEEDINGS of the 42d Annual Meeting held at Atlantic City, N. J., June 26–30, 1939, volume 39. American Society for Testing Materials, Philadelphia, 1940. 1,344 pages, illustrated, 9 by 6 inches, cloth, $6.00 to members, $9.00 to non-members. Contains summary of proceedings at the annual meeting, reports of the various committees, and technical papers, with discussions.

COSMIC RAYS. By R. A. Millikan. Macmillan Company, New York; University Press, Cambridge, England, 1939. 134 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. Three lectures delivered in 1936 and 1937 by Doctor Millikan are here presented in revised form. The first is on "the discovery of cosmic rays and its general significance". The second, "superpower particles", deals with the experimental technique for investigating them, and is illustrated by cloud-chamber photographs. The third describes investigations of the "earth's magnetic field and cosmic-ray energies".

PROBLEMS AND POLICIES IN INDUSTRIAL RELATIONS IN A WAR ECONOMY. A Selected, Annotated Bibliography. Revised edition, prepared by H. Baker. Industrial Relations Section, Princeton University, Princeton, N. J., May 1940. 30 pages, 9 by 6 inches, paper, $0.25. The books, reports, and articles listed in this bibliography of industrial organization in wartime cover conditions in the United States and Great Britain during the World War and the reconstruction period, legislative developments in the United States affecting current adjustment to a war economy, and discussions of current problems. There is an author index.

Transactions
Preprint of Technical Papers Comprising Pages 489-562 of the 1940 Volume

Electric Braking for Railroad and Urban Transit Equipment

F. H. CRATON
MEMBER AIEE

F. M. TURNER
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THE PURPOSE of this paper is to outline the present status of electric braking in the railroad and urban transit fields and to point out possible solutions of future braking problems particularly those arising from increasing speeds.

General

The science of train braking has progressed steadily with the development of railroad transportation. Improvements in air brakes along with improvements in motive power and rolling stock have made possible the steadily increasing speed and length of trains; in fact, the railroad industry as we know it today. With the exception of a few railway electrifications where regenerative electric braking has been applied, this entire development of braking on the railroads of this country has been, until very recently, that of the compressed-air system.

As the speed and length of trains have increased, the braking problem has become more and more difficult of successful solution. In freight-train operation, the problem is accentuated more by the length than the increased speed and has been one more of control than of dissipation of energy. This is because maximum speeds have been restricted both by tonnage handled per locomotive unit and by the design of rolling stock used. On the other hand, length of trains has increased to such an extent, it has been difficult to transmit the braking impulse from the locomotive to 100–150 cars in such a way as to avoid undesirably variable response, rough slack action, and damage to equipment and lading. A program is now under way involving application of improved brake equipment to approximately 2,000,000 freight cars to eliminate these conditions.

In passenger equipment, the problem of braking is more affected by increased speed than increased train length. A 20-car train is about the maximum handled and most trains are further restricted by traffic requirements and station-platform limitations. The use of spring buffers and other means of either controlling or eliminating slack, simplify the problem. The use of electropneumatic brakes on unit trains effects instantaneous transmission of the braking impulse to every car. The difficulty arises from the peak speeds now encountered—100 miles per hour or more—where desired retardation rates, braking ratios, shoe pressures, and rate of energy dissipation greatly exceed past requirements for safe and economical operation.

Associated with the high-speed deceleration problem is the requirement of higher-speed operation on down grades where, in mountain territory, railroad profiles require miles of continuous operation descending two per cent grades, imposing a heavy load on the brake equipment from the standpoint of continuous energy dissipation that is almost directly proportional to the higher speed.

These problems are serious and much research and development work is being done by the air-brake manufacturers to cope with them. Tied in with these problems is the question of the deleterious effect many claim high-speed braking has on wheel life and performance. This has led to experiments with various types of nontread friction brakes.

In the urban transit field schedule speeds have also been increased with a corresponding increase in braking rates as well as acceleration. While speeds are much lower than for heavy railroad operation, the requirement for more rapid acceleration is, nevertheless, an important factor. At the same time relief from excessive heating of the wheel treads by mechanical braking is essential to economical maintenance and safe operation.

Unlike heavy railroad operations, urban vehicles rarely require braking on long grades but are concerned principally with frequent and rapid decelerations for stops. Dynamic or rheostatic braking systems and electromagnetic track brakes are now being extensively applied to urban transit vehicles.

The successful dissipation of large amounts of energy is not the only problem in high-speed braking. Due to the high retardation rates required to hold stopping distances within prescribed limits, it is desirable to take advantage without wheel sliding of all of the wheel-rail adhesion possible throughout the complete deceleration. Opposed to this, is the fact that the braking force is directly affected by many transient phenomena, which cause it to change many times during a deceleration. Not only does this make necessary the use of devices to alter the braking ratio during a maximum deceleration, but also, because these phenomena are likely to differ in magnitude on different axles in the train due to condition of wheels, shoes, brake rigging, etc., the brake application should be such as to prevent wheel sliding on the axle most susceptible to it. Devices are now being tried which anticipate wheel sliding on each axle and automatically ease the brake shoe pressure when wheel sliding is imminent.

A precept which has governed the design of new braking equipment is that improvements must be of such a nature that they will function in complete harmony with existing apparatus and thus preserve the enormous investment in equipment already in service.

The foregoing remarks give a rough idea of the magnitude and complexity of the braking problem, particularly with respect to high-speed passenger operation. The following discussion will attempt to show the part which various forms of electric braking are playing in the railroad picture and what effect they may have on the further development of means to cope successfully and economically with this increasingly difficult problem of high-speed braking.

Paper 40-28, recommended by the AIEE committee on transportation, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 16, 1939; made available for preprinting December 28, 1939; released for final publication March 21, 1940.

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Braking a train from high speed to standstill usually takes the form of unproductive liberation of heat by the dissipation of kinetic energy created during acceleration. Braking on a heavy downgrade at constant speed produces the same result by dissipating potential energy created by hauling the train uphill previously. The natural function of a wheel appears to be to roll under load and not act as a medium for the dissipation of excessive amounts of energy at excessively high rates such as encountered frequently in the retardation of modern trains. Even though wheels have been employed at this task with considerable success, the demands have reached a point where other means are being considered for the dissipation of this energy.

Regenerative Electric Braking

The ideal braking system would be one which would transform into useful work all available kinetic and potential energy in the train not absorbed by normal train friction. As this would require a system of 100 per cent efficiency, it is obviously impossible but from a practical standpoint, such a system for constant-speed retardations is approached by regenerative electric braking which is available for most forms of straight electric locomotives, and is one of the several advantages which railroad electrification in general makes available.

This type of braking has been used on mountain electrifications exclusively since the benefits have been greatest in retarding heavy trains while negotiating long steep grades. Wherever used, this system has been very successful and has resulted in the following advantages:

Saving of approximately 15 per cent of total power required without regeneration, and 60 per cent on two per cent grade sections.

Elimination of brake shoe, wheel, and brake rigging trouble with attendant reduction in maintenance costs.

Smooth, continuous braking effort over long periods eliminating surges in speed with resultant wear and abuse of equipment.

Increased safety because the air brake is held in reserve so that in case of emergency stops, the air-brake system is charged and wheels and brake shoes are cool.

Increased comfort to passengers due to constant speed on grades and absence of noise due to grinding of shoes on wheels.

With this system, the braking power is limited by the driver weight of the locomotive and the capacity of the traction motors. In operation involving retardation of the train downgrade at constant speed, due to the fact the braking effort necessary is equal to the required tractive effort to haul the train up the grade minus twice the train friction, modern regenerative locomotives are capable of handling with leeway, any train downgrade which they can handle up the same grade. Grade sections also frequently include heavy curves which are fully compensated and this factor further reduces the braking necessary to hold a descending train.

Take for example a passenger train of 1,000 tons gross weight hauled by a 3,000-volt d-c locomotive recently put into service. The locomotive weighs 185 tons with 135 tons on drivers. The motoring and braking characteristics are shown in figures 1 and 2 respectively. The tractive effort required to handle this train up a two per cent grade is 47,000 pounds or 17.4 per cent adhesion, which gives a balancing speed of 50.3 miles per hour in the highest-speed motor combination. Retarding this same train down a two per cent grade requires 31,000 pounds braking effort or 11.5 per cent adhesion, which is attainable up to 67.5 miles per hour.

Track conditions, particularly curvature, will, of course, govern speeds in this type of operation, but the foregoing example shows the possibility of regenerative electric braking with a modern high-powered locomotive with respect to high-speed operation in heavy-grade territory. In this example, additional electric braking power is available if required, and with the air-brake system backing up the regenerative brake, safety is assured.

The regenerative electric brake can be used to advantage sometimes for light decelerations, the extent depending upon the grade, weight of train, and required decelerating rate. The bunching of slack and the smooth, quiet application of retarding effort is both beneficial to equipment and, in passenger service, a distinct advantage particularly to patrons in sleeping cars.

For retardation cycles approaching a full service or emergency application with air equipment, the regenerative brake, which is available on the locomotive alone, is entirely inadequate because of limitations in both driver weight and electrical capacity. For such decelerations, it is necessary to take advantage

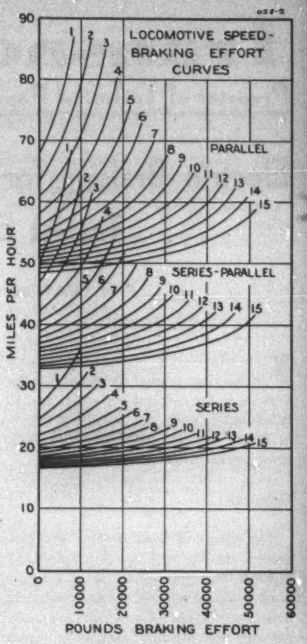

Figure 2. Speed-braking effort curves for a 185-ton six-motor electric passenger locomotive with regenerative braking

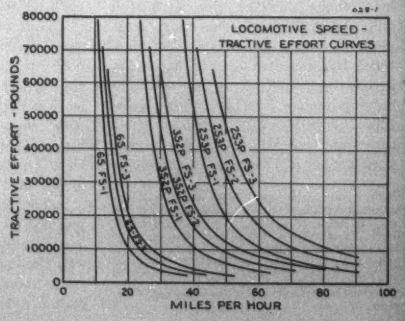

Figure 1. Speed-tractive effort curves for a 185-ton six-motor electric passenger locomotive

of the entire adhesive weight of the train. To appreciate this fully, consider the conditions involved in decelerating a 1,000-ton train from 80 miles per hour to standstill on level track.

At 80 miles per hour this train possesses a kinetic energy of approximately

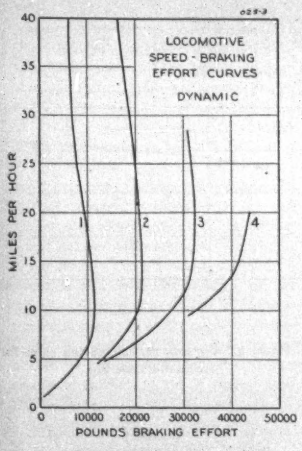

Figure 3. Speed-braking effort curves for a self-propelled locomotive with dynamic braking

428,000,000 foot-pounds, ignoring the rotational energy of wheels and axles. With a full service application of the air brakes, the deceleration will be at approximately two miles per hour per second average to standstill. On the basis of the train resistance cancelling the rotational energy during deceleration, which is essentially true, the average braking effort during the retardation cycle would be 182,000 pounds and the *average* dissipated horsepower 19,400. Taking the powerful locomotive represented by figures 1 and 2, this corresponds to a wheel-rail adhesion of 67 per cent and a braking horsepower 277 per cent of the maximum available.

In an emergency application at three miles per hour per second average deceleration, the average braking effort becomes 273,000 pounds, and the average dissipated horsepower, 29,100, corresponding to 101 per cent adhesion and 415 per cent of the maximum available braking horsepower of the locomotive.

These decelerations, which are not based on unusually severe conditions of either maximum speed or weight, give another insight into the magnitude of the energy to be dissipated and the resulting forces involved in the braking of high-speed modern trains.

Dynamic Electric Braking

Self-propelled locomotives using electric drive such as the Diesel-electric and steam-electric types can be equipped with dynamic braking which does not differ essentially from regenerative electric braking except that the energy must be dissipated in some manner on the locomotive rather than returned to the distribution system.

In some respects the dynamic electric brake has advantages the d-c regenerative brake does not have, in that the dynamic brake is flexible as to its characteristics. There are two types of braking characteristics, the holding brake and the stopping brake. The former has variable braking effort at constant speed and the latter, constant braking effort at variable speed. The regenerative electric brake on d-c equipment is of the holding-brake type inherently because it is tied down to constant voltage operation. The dynamic electric brake, however, can be designed to produce any desired characteristic by suitable arrangement of circuits, excitation, and external resistor values.

Figure 2 shows the characteristic curves of the regenerative electric brake on a d-c locomotive. The relatively flat shape means the locomotive can descend a variable profile at practically constant speed, automatically adapting itself to the changes in braking effort required.

Figure 3 shows a dynamic braking characteristic that is vertical and ideal for applying constant braking effort automatically throughout a deceleration. This can be approached with the regenerative brake in figure 2, but only by a skilled operator through constant manipulation of the braking controller, including shifting the motor combinations when required.

The 5,000-horsepower steam-electric locomotive built for the Union Pacific system, has a unique application of dynamic electric braking (figure 4). The unusual feature is the method of dissipation of electric energy generated during braking. The energy is delivered to a resistor consisting of sections of seamless stainless-steel tubing, through which water is circulated from the main power plant, the water being heated and in heavy braking duty partially converted into steam. The outlet of the resistor is connected to a separator from which hot water is returned to the hot well and steam to the main condenser.

The electric brake may be used alone or in conjunction with the air brakes. When used alone or with the air brake up to 48 pounds brake-cylinder pressure, the output is limited automatically to 4,800 kw to protect the motors from continuous overload down long mountain grades. From 48 to 100 pounds brake-cylinder pressure, indicating a stop is imminent and the demand for power limited in time, the output of the electric brake is graduated automatically up to 7,200 kw at the 100-pound cylinder pressure which corresponds to an emergency application on a modern electro-pneumatic straight air equipment as used on streamlined trains.

To date there have been no applications of dynamic braking to Diesel-electric locomotives in main-line service, although there is no reason why such braking cannot be applied. Experience with this type of braking on the Union Pacific steam-electric locomotive has emphasized the advantages of the system in retardations at constant speed or moderate decelerations, as well as safety at higher speeds in downgrade operation.

On a Diesel-electric the energy can be absorbed in resistors and the heat ultimately released to atmosphere through a system utilizing the engine cooling water and radiators. As alternatives, air-blast resistors might be used or resistors cooled by a separate fluid system employing a synthetic liquid of desirable characteristics with respect to specific

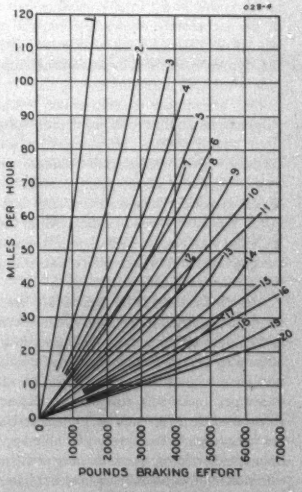

Figure 4. Speed-braking effort curves for 5,000-horsepower steam-electric locomotive (dynamic braking)

heat, boiling and freezing points, dielectric strength, inflammability, etc.

A miniature edition of such a dynamic brake was put in service recently on a 400-horsepower 20-ton Diesel-electric rack-rail locomotive for pushing a 12-ton locomotive with electric drive is geared for a peak speed of 120 miles per hour. As these top speeds increase, the braking problem becomes more and more acute. The kinetic energy in a train at 140 miles per hour is about double that in the same hour per second deceleration from 40 miles per hour down to approximately 7 miles per hour. At this speed the dynamic braking fades out rapidly and the air brakes are automatically engaged to assist the magnetic track brakes in main-

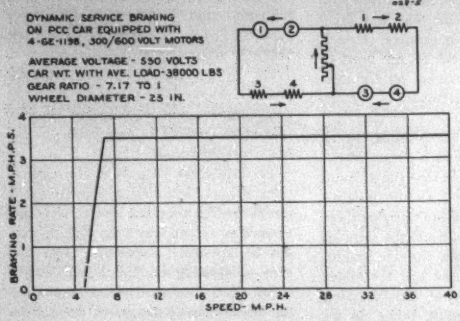
DYNAMIC SERVICE BRAKING
ON PCC CAR EQUIPPED WITH
4-GE-1198, 300/600 VOLT MOTORS
AVERAGE VOLTAGE - 550 VOLTS
CAR WT. WITH AVE. LOAD-38000 LBS
GEAR RATIO - 7.17 TO 1
WHEEL DIAMETER - 25 IN.
BRAKING RATE - M.P.H.P.S.
SPEED- M.P.H.

Figure 5. Dynamic service braking curve for PCC car

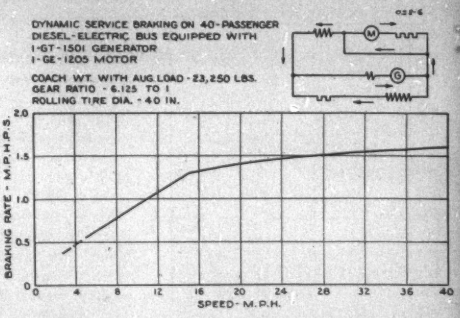
DYNAMIC SERVICE BRAKING ON 40-PASSENGER
DIESEL-ELECTRIC BUS EQUIPPED WITH
1-GT-1501 GENERATOR
1-GE-1205 MOTOR
COACH WT. WITH AUG. LOAD - 23,250 LBS.
GEAR RATIO - 6.125 TO 1
ROLLING TIRE DIA. - 40 IN.
BRAKING RATE - M.P.H.P.S.
SPEED- M.P.H.

Figure 6. Dynamic service braking curve for Diesel-electric bus

observation car up and retarding it down the Manitou & Pikes Peak Railway which negotiates Pikes Peak in Colorado. The braking problem on this nine-mile road is severe because the average grade is 16 per cent and the maximum 25 per cent and absolute reliability is essential. The use of dynamic braking, in which power is dissipated in air-cooled resistors in the locomotive allows full control of the speed throughout the descent with the dynamic brake alone except at stopping when this brake fades out.

The use of an electric brake would eliminate immediately all problems arising from sliding-friction phenomena, wheel slipping, and temperature changes in shoes. Because of its prompter action, fewer variable characteristics, and flexibility, it is effective more quickly than the air brake and can be used as well to assist the conventional brakes where high-speed demands exceed their capacity.

Electric braking so far has hardly been tried in the streamliner field where speed is the outstanding factor. Today we hear 100 miles per hour talked of freely as a normal nominal top speed just as 60 miles per hour was commonly referred to as a measuring stick of high speed a few years ago. Tomorrow 100 miles per hour maximum on the rails may well be common, and we shall be looking at higher speed levels again as indicative of the trend of ultramodern railroad equipment. Even today, the modern self-propelled train at 100 miles per hour. As this trend to higher speeds develops, the necessity for new braking methods will become increasingly pronounced. The electric brake is a potential candidate to meet this necessity; in fact, it may open the door to ultrahigh-speed operation, for without suitable braking equipment, such operation is impractical.

Electric Braking in Urban Transit Service

In recent years, electric braking also has been used in urban transit service, which is quite different from heavy main-line railroad operation. Urban service involves relatively light vehicles, such as the Electric Railway Presidents' Conference Committee or "PCC" car, the single-motor trolley coach, and the gas-electric or Diesel-electric bus.

The PCC car utilizes entirely new propulsion equipment to obtain high rates of acceleration and braking, and resilient wheels which have rubber inserts between the wheel tire and hub to reduce wheel and rail noise. This design was a factor in the adoption of a braking system comprised of dynamic braking, magnetic track brakes, and conventional air-operated wheel brakes properly blended by a single brake pedal.

During a typical service stop of a PCC car weighing approximately 38,000 pounds with seated load and decelerating at $4^3/_4$ miles per hour per second, the traction motors contribute $3^1/_2$ miles per hour per second of dynamic braking and the magnetic track brakes $1^1/_4$ miles per taining the braking rate to standstill. A feature of this braking sequence is the fact that the air brakes are called for at the same pedal by which dynamic braking is established, but the air brakes are held off automatically so long as the dynamic braking builds up to the desired rate. Thus, if the dynamic brakes should fail to build up for any reason, the air brakes would be available immediately to assist the magnetic track brakes in braking the car. Emergency stops at a rate of 7 to 8 miles per hour per second are obtained by increasing the dynamic braking to 4 miles per hour per second and the magnetic track brakes to 3 or 4 miles per hour per second deceleration, by depressing the brake pedal to its lowest position. An infinite number of intermediate braking rates between one mile per hour per second and emergency rate are available by depressing the brake pedal a corresponding amount.

Dynamic braking was selected as the primary brake on PCC cars because it is entirely independent of the trolley power in case of dewirement and because it requires relatively little control equipment in addition to the accelerating control, much of which is also used during the braking cycle. In addition, an emergency dynamic braking position is provided on the manually operated motor reverser. When the reverser is placed in this position, the traction motors are short-circuited to provide a very effective

dynamic emergency brake if all other brakes should fail.

Each magnetic track brake consists of a large electromagnet mounted on a long, narrow shoe that is suspended parallel to and directly over the rail between the two wheels on each side of each truck. Four such magnet shoes are mounted on a car. When the electromagnet coil is energized, the shoe is pulled against the rail by its own magnetic action and the resultant friction of the brake shoe on the rail exerts a braking effort on the car. The relative effect of this retarding force is dependent upon the magnetic strength of the electromagnet coil, which is controlled by depressing the brake pedal. The track-brake coils are energized from a storage battery in order to make this brake also independent of the trolley power in case of dewirement. This brake is not usually cut off before standstill is reached, nor does it fade out at low speeds. However, provision is made to release it when the brake pedal is latched down to continuously engage the air brakes for prolonged parking, in order to eliminate needless drain of energy from the battery.

The use of electric braking as the primary brake on PCC cars eliminated the problem of using air-operated wheel brakes for service stops at high rates of deceleration with the attendant dissipation of large amounts of heat in the car wheels. In fact, some of the newest cars use a spring-applied clasp brake to supplement the electric brakes at low speeds and for parking, and thus eliminate entirely the use of air-operated wheel brakes. The same principles of electric braking utilized so successfully on PCC cars have recently been applied and have materially simplified the problems of equalization and prompt response of braking effort on all axles of a multi-section subway-elevated train (figures 5 and 6).

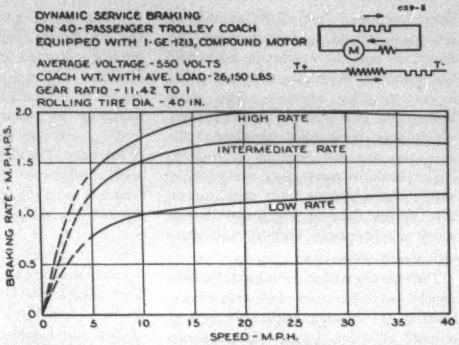

Figure 8. Dynamic service braking curve for single-compound-motor trolley coach

Electrically propelled automotive-type urban transit vehicles, particularly the trolley coach, have presented a more serious braking problem than mechanically driven busses, due to the higher rates of acceleration and deceleration demanded from electric drive and due to the free-wheeling characteristic of electric drive in which there is no engine compression to assist the wheel brakes. The use of higher ratios (power-to-weight) with electric drive in the last few years, coupled with the fact that the physical size of wheel brakes has reached practical limits, led to the introduction of the compound-wound trolley-coach motor and automatic control equipment designed especially for regenerative and dynamic braking and speed control, and to the development of new series-wound motors and control equipments designed especially for dynamic braking.

It is characteristic of the compound-wound motor that, if the shunt-field strength is increased while motoring at a given speed, the motor, driven by the inertia of the load, begins to regenerate and exert a braking effort on the load until a lower balancing speed corresponding to the stronger shunt-field strength is attained, at the same time returning power to the line.

This principle of shunt-field control is utilized with the modern compound-wound trolley-coach motor to provide a number of balancing speeds over the upper half of the vehicle's speed range, with regenerative braking automatically obtained during deceleration from one balancing speed to another or while holding the coach at any one of these balancing speeds during descent of a grade.

The compound-wound motor with the shunt-field winding separately excited from the trolley has ideal characteristics for dynamic braking (figure 8). By opposing the series and shunt fields, a differential action is obtained which prevents the imposition of excessive strains on the rear axle or gearing. Dynamic braking and air braking are applied by a single pedal. Maximum dynamic braking is obtained at approximately one-half pedal travel; and at the same time a small amount of air is admitted to the brake cylinders. Further movement of the pedal maintains maximum dynamic braking until approximately 85 per cent of the air braking is being applied. Dynamic braking is then reduced to the minimum and 100 per cent air braking applied. This operating sequence permits maximum utilization of dynamic braking without applying excessive braking to the rear wheels during an emergency stop.

Paralleling the development of the compound-wound motor is a new series-wound motor for trolley coaches which has been designed especially for dynamic braking. This development was made possible largely by the introduction of a practical, automatic acceleration control which has been adapted for use during dynamic braking automatically to commutate the braking resistance in series with the motor to hold the desired ac-

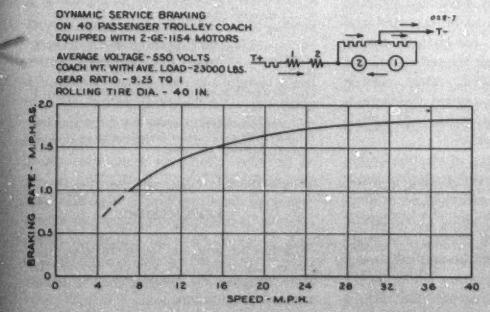
DYNAMIC SERVICE BRAKING
ON 40 PASSENGER TROLLEY COACH
EQUIPPED WITH 2-GE-1154 MOTORS
AVERAGE VOLTAGE - 550 VOLTS
COACH WT. WITH AVE. LOAD - 23000 LBS.
GEAR RATIO - 9.25 TO 1
ROLLING TIRE DIA. - 40 IN.
T+
T-
BRAKING RATE - M.P.H.P.S.
SPEED - M.P.H.

Figure 7. Dynamic service braking curve for two-motor trolley coach

celeration rate. An infinite number of intermediate braking rates between the minimum and the maximum are available merely by depressing the brake pedal a corresponding amount. The same brake pedal also controls the air brakes, which may be applied simultaneously with the dynamic braking to provide higher braking rates than are possible with dynamic braking alone, or to assume the braking duty at low speeds below which the dynamic braking automatically fades out.

The past year or two has also advanced the application of electric service braking to existing cars and trolley coaches of older design. The scheme most universally employed for this purpose consists essentially of connecting load resistors across the motor armatures and connecting the armatures in series with the motor fields in such a manner that, when the fields are excited from the trolley, the generated voltage of the motor armatures opposes the applied trolley voltage. This connection results in a differential action which automatically increases the field strength as the armature voltage decreases with vehicle speed in order to maintain a substantially constant rate of deceleration over a wide vehicle speed range. This form of dynamic braking is advantageously applied to older-type cars and trolley coaches having nonautomatic control and excess motor capacity.

Dynamic electric holding brakes were practically standard equipment on the earliest gas-electric busses with dual-motor drive, as these busses had only two-wheel mechanical brakes. However, the holding brake as applied to these vehicles was not designed to assist the wheel brakes during a service stop, but was intended merely for holding the bus at a predetermined speed on some specific grade. Since the introduction of the modern single-motor equipment for gas-electric or Diesel-electric busses was subsequent to the universal adoption of four-wheel air brakes for railless urban vehicles, the dynamic holding brake has been retained only where unusually long or severe grades are encountered, complete reliance being placed on the air brakes in most cases.

However, increased size of busses and installation of larger engines, as well as a demand for higher schedule speeds, have recently promoted the development of a fully automatic electric service brake to supplement the air brakes on modern gas-electric and Diesel-electric busses. This form of dynamic braking utilizes power obtained from the main generator to excite the fields of the traction motor, the armature of which has a braking resistor connected across it. The amount of motor field excitation taken from the generator is automatically regulated to maintain an approximately constant braking rate over the entire speed range of the bus. The electric braking may be applied whenever the engine throttle is returned to its idling position, in order to simulate the retardation effect of engine compression, or it may be applied by initial movement of the brake pedal. It is automatically cut off at low bus speeds. Test installations indicate a material improvement in the life and maintenance of the wheel brakes on Diesel-electric busses equipped with this type of dynamic service brake.

In all cases where modern electric service braking has been applied to supplement wheel brakes, the life and maintenance of the wheel brakes on electrically propelled vehicles has been equal to or better than the life and maintenance of wheel brakes on similar mechanically-driven equipment, in spite of the higher schedule speeds and higher deceleration rates normally used on electrically-propelled vehicles. The use of higher rates of electric braking on trolley coaches and on electrically-driven busses is not recommended, however, because the braking must all be done on the rear axle and would thus cause the rear wheels to assume a very major portion of the total braking duty. This would cause the vehicle braking characteristics to approach the obsolete performance standards of two-wheel brakes which, for obvious reasons, the industry saw fit to discard years ago.

Conclusions

Operating experience in recent years clearly establishes the importance of electric braking as a supplementary system both in heavy railroad operation and for urban transit. A continued demand for higher speeds is to be expected and the limitations of mechanical brakes without excessive weights and costs have already been indicated. Thus, electric braking may easily augment the increasingly drastic requirements of electric modern motive power.

Of the several types of electric brakes discussed, regenerative braking is available for electrified railroads or trolley-coach lines while dynamic or rheostatic brakes, eddy-current brakes, and magnetic track brakes can be applied as well to self-propelled vehicles. Under heavy braking conditions, regeneration returns appreciable amounts of power to the line. Exceptionally favorable conditions such as a three per cent continuous grade may return regenerated power amounting to as much as 70 per cent of that used for motoring.

Dynamic braking delivers electrical energy to resistors where it is dissipated in the form of heat. Eddy-current brakes accomplish the same result by use of a self-contained independent device attached to the motor frame and coupled to the armature shaft. Eddy-current brakes are operating successfully on rapid transit equipment but in general the extra cost discourages their general use. Dynamic brakes on the other hand make use of the existing motor as a generator and usually the resistor equipment normally used for acceleration.

Magnetic track brakes while simple and comparatively inexpensive are only justified where rapid and frequent decelerations are absolutely essential to the performance of a given schedule. Present applications are limited to PCC cars and rapid transit trains.

Bibliography

1. Regenerative Braking for Direct-Current Locomotives, **A. Bredenberg, Jr.** AIEE Transactions, June 1926.

2. High-Speed Air-Brake Tests on the Burlington Zephyr, **Joseph C. McCune.** Western Railway Club *Proceedings*, March 1935.

3. Mastering Momentum, parts I and II, **L. K. Silcox.** Massachusetts Institute of Technology, April and December 1936.

4. The Friction of Railway Brake Shoes at High Speed and High Pressure, **Herman J. Schrader.** Bulletin No. 301 of the University of Illinois Experiment Station.

5. Electrical Equipment of the Union Pacific Steam-Electric Locomotive, **M. R. Hanna and J. F. Tritle.** AIEE Transactions, volume 59, 1940, see annual index for page numbers; see also Electrical Engineering, volume 58, October 1939, pages 407–13.

6. Braking High-Speed Trains as an Engineering Problem, **Joseph C. McCune.** *Mechanical Engineering*, August and September 1939.

7. Regeneration on Tramcars, *Electric Railway Bus and Tram Journal*, November 14, 1930.

8. Regeneration on Electric Railways, Institute of Transport. *Electric Railway Traction* (supplement to *Railway Gazette*) March 9, 1934.

9. Compound Motor Tested on Two French Systems, *Electric Railway Journal*, February 1931.

10. Regenerative Control of Street Cars, **L. MacKinnon.** Glasgow, *Electric Traction*, August 1932.

11. Power Economy by Regeneration, **W. J. Clardy.** *Transit Journal*, April 1934.

12. Regenerative Control for D-C Railways, *Electric Railway Traction* (supplement to *Railway Gazette*), January 10, 1936.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

Network Coupling by Means of Static Electronic Frequency Changers

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FELLOW AIEE

DURING the last few years several attempts have been made, especially by some foreign railways, to find ways and means to feed their 11,000-volt $16^{2}/_{3}$-cycle railway trolley system directly from a commercial 50-cycle power source by means of a simple device, or then to have the locomotives equipped with such apparatus which would permit using power at the latter frequency fed directly to the trolley line. In other words, it was felt that many advantages could be gained if the trolley line could be fed, directly, or over a simple converter, from any commercial power network which would be adjacent to the railroad's right of way. This desire led to the development of the 50-cycle series commutator motor by the Siemens Schuckert Company, a 50-cycle converter cascade motor by the Krupp Company, and to the converter locomotive by Von Kando. It also led to the design by several companies in Europe of a locomotive with a built-in mercury-arc rectifier for converting the 50-cycle power fed directly to the trolley line into direct current suitable for standard railway motors.

Furthermore, studies were made using a commutatorless motor with a mercury-arc rectifier. The development of this motor, having no commutator but using a rectifier for commutation and able to operate on commercial frequency, was, however, abandoned in its early stages, as far as its use on a locomotive went. However, it may be said that since single-anode tank rectifiers of large capacity are now available, a more economical connection for the commutatorless motor could be employed than was considered when the first investigations were made.

The operation of these various systems proved successful from a technical point of view, but they were found less advantageous from an economical and maintenance standpoint.

At this time, as briefly referred to above, still another system permitting the use of power of conventional frequency was under careful consideration, namely, using a rectifier on the locomotive converting 50-cycle power fed directly to the trolley system into direct current and supplying it to standard railway motors. Finally four locomotives of this design were built. Three of them are operating on the Hoellental railroad system. This system was originally projected for a trolley voltage of 15 kv but had to be raised to 20 kv in order to compensate for the high inductive drop at 50 cycles. The locomotives were equipped with standard series motors, a rectifier and transformer, and devices for voltage control, etc. The 50-cycle power supplied to the trolley system from a conveniently available power line is stepped down and converted into direct current by the transformer and rectifier on the locomotive.

However, before the studies undertaken by four companies in connection with these locomotives were very far advanced, it was found that the grid control, which at first thought appeared extremely simple, became quite involved. One company even abandoned the idea of controlling the voltage by means of grids and introduced tap changing under load equipment for regulating the anode voltage of the rectifier, and thus in turn the direct voltage supplied to the motor.

Simultaneously with this development, attempts were made to develop a static frequency changer using grid-controlled mercury-arc rectifier-inverters (electronic rectifier-inverters). This method would also make it possible to take power from any commercial network, convert it and feed the trolley system with a frequency suitable for a-c railway motors.[1-6] Such devices would be static and some of them would permit flexible coupling between a three-phase 60-cycle, and, for instance, single-phase 25-cycle trolley systems. Tests[6] with such frequency changers were started over six years ago, and after extensive experiments with sets of a capacity of 500 to 1,000 kw, a commercial installation was finally erected near Basel, Switzerland, feeding power into the $16^{2}/_{3}$-cycle trolley system of the Wiesenthal Railroad, Germany, from a 50-cycle network.[8,17,19]

The object of this paper is to discuss such methods of frequency changing using electronic rectifier-inverters which would make it possible to transform three-phase power of 60 or 50 cycles into 25 cycles, the frequency commonly used by the railroads in the United States. The other systems as used today in Europe are briefly referred to and discussed only where they have a bearing on the systems suitable for obtaining 25-cycle power.

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1. For all numbered references, see list at end of paper.

Rotating Versus Static Frequency Changers

The phenomena taking place during conversion of electric energy from one frequency to another will be discussed briefly in order that the arguments in favor of methods using electronic converters can be easily followed, and so that some of the theoretical considerations put forward in several articles referred to below can be fully appreciated.

We may recall the fact that the energy furnished by a three-phase network, with a symmetrical three-phase voltage system, normally supplies a constant power flow in spite of the fact that in each individual phase the voltage and current change according to a sine wave. Power from a single-phase network, however, pulsates with twice the frequency of the induced voltage and current, which, as is well known, is an inherent characteristic of such systems. The instantaneous power demands of the two systems are not equal. Therefore, the supply of power from a network of commercial frequency to a single-phase railway system, necessitating conversion of energy from 60 to 25 cycles, means the electrical coupling of two power systems, each of which has quite a different characteristic of its natural flow of energy.[9]

Let us first analyze the power relation in case a three-phase single-phase motor generator set is used for coupling such systems. The power absorbed by the motor from the three-phase 60-cycle system shall be assumed to be constant and is illustrated by T in figure 1*b*. T is the summation of the power furnished by each phase X, Y, W, of the three-phase system. The power demand of the single-phase network on the three-phase network is shown in figure 1 by curve S, which in case of a mechanical frequency changer will always be active. In other words, in such a frequency changer no reactive power can be transmitted from one to the other system, and the same condition holds true

for a circuit as shown in figure 2. From figure 1*a* it can be seen that the single-phase energy S pulsates about a mean value T with a frequency equal to twice that of the frequency of the current i and voltage e of this system. The mean power of the single-phase system must be equal to T as the loads of the two machines average the same over one cycle, but, as said above, are not the same at each instant of the cycle. It will therefore be seen that during certain intervals (*a*), for instance, single-phase energy equal to the horizontal hatched area will have to be supplied from a source other than the three-phase system, while during the intervals (*b*), the same amount of energy has to be absorbed and stored in some way or other in order that the three-phase energy supply may be constant (equal to T). In other words an energy reservoir will be necessary to balance the available and required power. Curve S_1 shows, for a few cycles, the magnitude of energy which has to be taken care of at each instant by certain means (accumulators) capable of absorbing and freeing energy.

In the case of a motor generator set the rotating masses will automatically take care of the excess energy during period (*b*) and release it during period (*a*). However, it must be realized that this will only take place if the speed varies or deviates from the mean value N as shown in curve

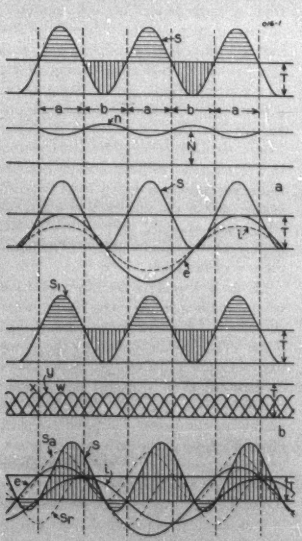

Figure 1. Energy relation between three-phase, single-phase systems of frequency converters

n (figure 1*a*). In other words, during the interval (*a*), the speed of the rotating masses is being advanced, while during interval (*b*) the speed will decrease over the mean value N.

Therefore, a rotating frequency changer (motor generator set) is able, with its normally inherent rotating masses, to take care of the surplus, or lack, of energy as compared to the mean value T, since the rotating masses permit storing and supplying energy. The three-phase motor will, therefore, draw constant energy from the 60-cycle network in spite of the pulsating character of the single-phase load, but the speed will fluctuate slightly with the frequency of the pulsating single-phase load.

The power supply for conversion of three-phase to single-phase current by means of an electrically controlled rectifier-inverter is illustrated in figure 1*b*. The power demand S oscillates at twice the single-phase frequency as above, T being the mean value and S_a the active and S_r the reactive component of power demand from the single-phase supply. Both were taken to be equal, representing a power factor of approximately 0.7. In the case of a frequency changer using an electrically controlled rectifier-inverter, no inherent means are available to permit storing and releasing of power at the frequency impressed by the single-phase load characteristic. Therefore, with such equipment the power oscillations are transferred to the three-phase network, which will be loaded with currents departing from sine waves and of frequencies foreign to the network frequency. This will result in an increase in reactive power, harmonics, and a negative component in the three-phase current system which will in turn affect the efficiency factor.

The above condition can only be corrected if means are used to take care of the differences between the instantaneous power demands of the systems as is done inherently in the case of a mechanical frequency changer. Such energy-storing equipment can be built up using a battery of capacitors and reactors (a resonant circuit). However, due to the fact that the intermediate d-c circuit of such an electronic converter, see figures 3 and 4, has a superimposed alternating current of 360 cycles (if a 6-phase electronic converter is used) and 720 cycles (if 12 phases are used), the smoothing or storing equipment may have to be of fairly high capacity. The use of capacitors and reactors forming a resonant circuit, even if of large capacity, introduces very little additional losses, as the energy can be kept oscillating between capacitors and reactors, consuming very little power. In case it is found advisable that the single-phase power energy oscillations may partly be transmitted back to the three-phase system, in other words, if T may vary, then the capacity for the storing equipment (capacitors and reactors) becomes relatively small. However, due to the recent developments of static capacitors for power-factor-improving equipment, the cost of such storing equipment is no longer prohibitive, and enough capacity may be provided to obtain a constant energy flow from the three-phase network as shown by T.

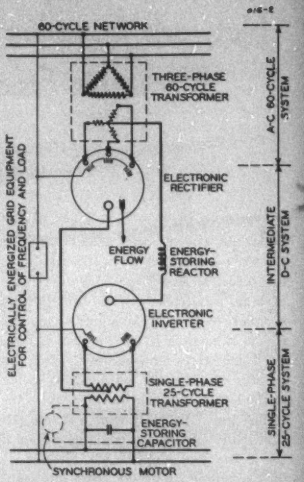

Figure 2. Fundamental circuit diagram for an electronic frequency converter with intermediate d-c step

Electronic Frequency Changer With Intermediate D-C Step

Flexible Indirect Coupling Between Systems

The simplest method for effecting a flexible coupling of a-c systems of different frequencies by means of electronic rectifiers and inverters is shown in figure 2. This system consists of a rectifier, a reactor, and an inverter. Three functions are necessary: First, the a-c power of 60 cycles is rectified into d-c power; second, the d-c power is inverted into 25-cycle single-phase power, and third, the difference between the instantaneous power demand of the single-phase system and the three-phase supply has to be balanced by an energy accumulator, which may consist of a reactor and a capacitor. The reactor

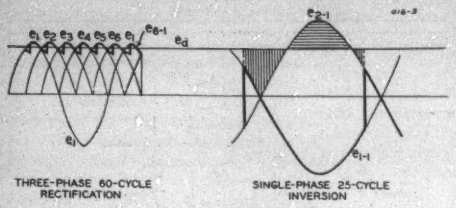

Figure 3. Relationship between single-phase voltage and intermediate direct voltage obtained from six-phase system

e_1, e_2, e_3, e_4, e_5, e_6, e_1, etc., represent phase voltages of the 60-cycle six-phase system. e_{1-1} and e_{2-1} represent voltage waves of the 25-cycle single-phase full-wave system. e_d represents the intermediate direct voltage of the rectifier inverter

is inserted between the rectifier and inverter, and takes care of the differences of the direct voltages e_{6-1} and e_{2-1}, figure 3. The voltages e_{6-1} and e_{2-1} refer to a six-phase rectifier system and a single-phase inverter system. For further data on rectifier and inverter operation, see bibliography.[13,14,23,26] The above arrangement does not allow reactive power to be fed back to the three-phase system, and only active energy can be transferred from the three-phase to the single-phase network. The reactive power would therefore have to be taken care of by a static or a synchronous condenser connected to the single-phase system.

The first two steps, namely, converting power from alternating current to direct current and from direct current to alternating current, have been done separately in many installations during the last few years and a great deal of experience was recently gained during extensive field as well as factory tests in connection with inversion of direct current to alternating current by means of grid-controlled rectifiers.[11,21,22] These tests have demonstrated that the flexibility between two a-c networks is fully maintained and no instability resulted no matter how large and sudden a change in frequency took place.

It may therefore be realized that at this time a frequency-changing set of great reliability can be built by utilizing the experience gained in some of the high-voltage rectifier and inverter installations briefly referred to later on.

Electronic Frequency Changer Without Intermediate D-C Step

(a). Flexible or Rigid Direct Coupling of Systems

The converter referred to above could be built up by using either single-anode or multianode tank rectifier and inverter; the one discussed below necessitates the single-anode tank arrangement. Figure 4 shows the basic circuit diagram of such equipment, consisting of a transformer and 12 single-anode grid-controlled rectifier-inverters; one set having their cathodes and the other set their anodes connected to one side of the single-phase system. Each pair of tanks connected to the same secondary winding constitutes a switch, in other words they permit current to flow in either direction. Let us assume that the grids of tubes R_1 permit current to flow while all other anodes are blocked, then the transformer winding 1 is connected to the single-phase system. After a certain period this set of tubes is blocked and set R_2 is released, thus phase 2 of the transformer may supply current. After another period of time the next phase, 3, is brought into play, and then 4, 5, etc. Figure 5 shows the voltage of each phase, and below the arc current which is commutated from each anode to the anode of the succeeding phase as the impressed alternating voltage of this phase becomes more positive than that of the phase carrying the arc. It would have to be arranged, therefore, that the grid-control equipment permits the flow of current according to the time interval t_1 to t_{14}. This results in sections of voltages e_1 to e_6 being made available and joined to the heavy-line curve which becomes the voltage e_s of the single-phase system. The flow of current through the individual tubes can be seen from the second curve of figure 5 for the case where the single-phase voltage and current are in phase.

The frequency ratio between e_1 to e_6 and e_s as shown in figure 5, upper curve, is about 3:1. However, as can be seen from the voltage curves below, any frequency ratio may be obtained, as any number of sections e_1 to e_6, or e_1 to e_6+e_1, or e_1 to $e_6+e_1+e_2$, etc., of the transformer phase voltages can be built up to produce the

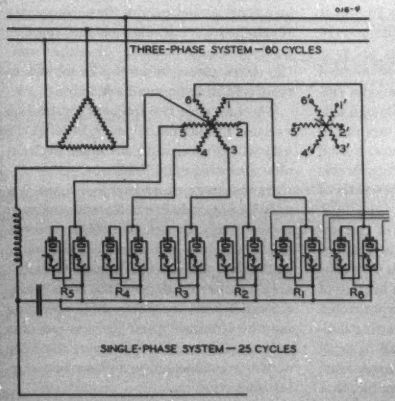

Figure 4 (left). Fundamental circuit diagram of an electronic frequency converter

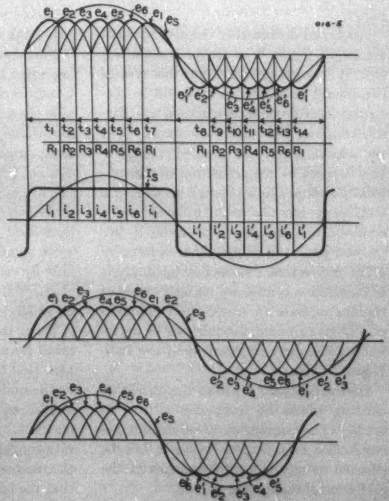

Figure 5 (right). Formation of single-phase voltage and current waves for different frequency ratios in an electronic frequency converter

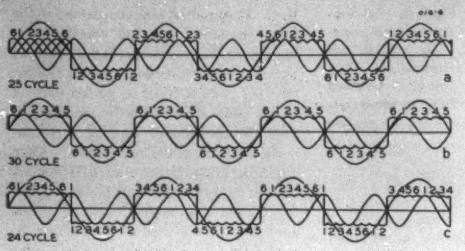

Figure 6. Diagram showing the firing of anodes for various frequency ratios in a flexible frequency converter

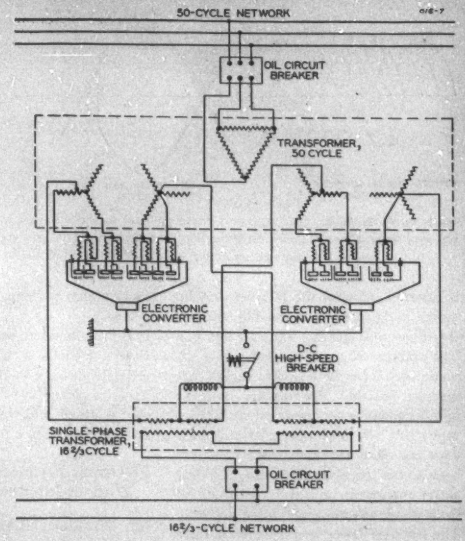

Figure 7. Fundamental circuit diagram for a rigid frequency converter

desired single-phase voltage e_s. A further consideration of these curves will show also that a change in the frequency of the three-phase voltage still permits obtaining a constant single-phase frequency. The flexibility of this type of frequency changer with electronic equipment will be analyzed still further below using figure 6.

As is well known the firing of the anodes can be controlled by means of grids in such rectifier tubes and therefore the voltage curve e_s in figure 5 could be made to resemble more closely a sine wave by retarding or accelerating the firing of some of the anodes.

The scheme[3,4] of employing a transformer with a modified secondary winding (see figure 4, system 1′, 2′, 3′, 4′, 5′, 6′) cannot be used unless the ratio of the frequencies is for instance 3:1, as is the case in Europe between the conventional 50-cycle power and the $16^2/_3$-cycle railway systems. Furthermore, this permits only a rigid coupling between the two systems. For these reasons no further consideration will be given to these methods in this paper.

Analyzing still further the arrangement shown in figure 4 of frequency conversion, it is quite apparent that this type of equipment and others which will be discussed later do provide a completely flexible coupling between two systems. For the sake of brevity no detailed consideration is given in this discussion to the subject of commutation between sections of a rectifier system nor to the influence upon commutation in case a potential is impressed upon the single-phase system by other converters. However, an analysis of conditions caused by various ratios of the three-phase to single-phase frequencies is given below for purpose of determining the duty imposed upon the individual anodes.

Part *a* of figure 6 shows the condition existing when the frequency ratio is 60 to 25. The commutation of current between the two rectifier systems can be effected at any instant by means of the grid-control equipment.

Part *b* illustrates the condition when the frequency ratio is 60 to 30. Here we see that each of the six anodes fires only once during the active period of either system; further, we also see that the same anodes bear the entire burden of each commutation, and each of the others always carried the current during the same part of the active cycle of its system. From this it is obvious that the duty on the anodes within one of the systems cannot be equally distributed, and the anode subjected to the most severe duty will govern the rating of the rectifier.

Part *c* indicates the relationship existing when the frequency ratio is 60 to 24. Conditions in this instance are more favorable than for the ratio of 60 to 30, but it does have some undesirable characteristics. Investigation shows that the burden of commutation is now divided equally among four of the six anodes employed in each system, and although this does limit the capacity of the rectifier to some value less than it would have if used only for rectification, the reduction in this case is less than for the frequency ratio of 60 to 30.

From the above discussion of the unusual frequency ratios it may at first appear that the ratio of 60 to 25 is very near to the undesirable condition of loading of anodes encountered when it approaches 60 to 24. However, before drawing definite conclusions it might be well to recall the reason for developing such apparatus; that the coupling be entirely flexible, that is, that the frequency ratio may be a variable. With this in mind let us consider what determines the frequency of the two systems; in the case of the three-phase system it is without exception dependent upon the speed of the prime movers driving the generators, while the single-phase system may or may not include rotating equipment. The three-phase systems are well known to maintain a constant frequency; on the other hand, traction systems do allow relatively large variations, the reason being that if compared to the supply capacity, great power demand fluctuation occurs. In the case where no rotating equipment is supplying energy to the single-phase system, its frequency will be a function not only of the active power requirements, but also of the reactive power demand as well. In either case, the single-phase frequency is subject to relatively wide fluctuations.

The fact that the frequency ratio is a variable eliminates the possibility that the unit will be subject to sustained undesirable operating conditions.

Furthermore, from part *b* of figure 6 it may be concluded that the conversion of power from a 50-cycle to a $16^2/_3$-cycle system (3:1) does not provide a favorable utilization of the rectifier-inverter and it may be concluded from the above consideration that more favorable operation may be obtained when 60-cycle power is converted into 25-cycle power, since the anodes are subjected to a lower duty during commutation.

(b). Rigid Indirect Coupling of Systems

Figure 7 shows the diagram of connections of such a type of frequency changer with the electronic converters and the three-phase and single-phase transformers. This system has, however, a serious inherent disadvantage—namely, the coupling is not flexible and therefore any change in frequency on one system will automatically affect the frequency of the other. However, in spite of this drawback such equipment has been installed to supply a small railroad with $16^2/_3$-cycle current. The set is rated 3,600 kva continuous load, 2,520 kw (power factor 0.7) 4,000 kva one-half hour, and 6,000 kva, one minute, and has been in commercial operation since December 1936. The unit furnished the entire load for over a year for this branch railroad which was up to then supplied by means of two motor generator sets, each rated 2,100 kva. Therefore, these two motor generator sets were used only for standby units, but it was contemplated to have one working in parallel with the static frequency changer as soon as this method of conversion has proved satisfactory and could then be reconnected in such a way that it could work in parallel with any other converter, whether of the mechanical or another electronic type. The original setup as indicated above was such that the frequency of the single-phase output was a function of the frequency of the three-phase supply system. In other words, the coupling of this system as originally used was not flexible and parallel operation of different units could not be accomplished without using a connection similar to the one which will be explained below. The frequency changer was supplied by a 45-kv 50-cycle transmission line, and therefore the rectifier transformer was provided with a 45-kv delta primary winding. The voltage of the intermediate d-c system of the frequency changer was chosen at 2,000 volts and does not depend upon the voltage of either the three-phase or the single-phase network.[8,17,18,19,20]

The grid control of this unit is such that a slight inaccuracy in the adjustment of the firing period may make the unit completely inoperative. Furthermore, this method of frequency changing is very limited, as stated before, as it does not provide a flexible coupling, produces an unequal loading of the anodes, and necessitates a tank with an abnormal number of anodes. The advantages which may be stressed are long firing time of the anodes, and the possibility of furnishing wattless power from one network to the other.

Two things, however, were definitely demonstrated by the installation of this type of static frequency changer, namely, that it requires less space and has less weight, both of which reduce the cost of the building and foundations. Furthermore, the efficiency at light load was considerably higher than the one which could be obtained with a mechanical converter.

It may be mentioned that right from the beginning considerable difficulties were experienced due to the fact that the communication systems were exposed to the trolley, as well as feeder system, both of which showed considerable current and voltage wave distortion from the rectifier-inverter. This situation was corrected by means of filters. Further on will be outlined some schemes and methods which may be employed in order that the inductive co-ordination of power and telephone systems may be obtained for large installations of static frequency changers without using filters.

(c). Flexible Indirect Coupling Between Systems

The static frequency changer discussed below has recently been perfected and is based on a somewhat different principle than the arrangements described above. It attracted considerable attention among European engineers, especially due to the fact that it permits flexible coupling of two a-c systems of any frequency, without appreciable distortion of the current and voltage waves. Such a frequency changer was recently put in commercial operation for coupling an a-c three-phase 50-cycle system with a single-phase $16^2/_3$-cycle trolley system, converting as much as 3,000 kw. A similar electronic converter has been placed in operation, of a capacity of 1,600 kw, coupling a 50-cycle three-phase system with another three-phase system which has a frequency of 42 cycles. Both installations have already given several thousand hours of satisfactory service.[9,10,24]

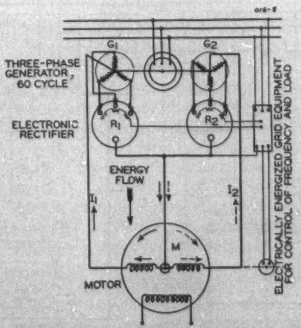

Figure 8. Simplified circuit diagram for demonstrating flexibility of electronic frequency converter

Let us therefore describe this system more fully by means of a simplified circuit, figure 8. This circuit may have no practical value, but will permit ready analysis of all the phenomena with which we shall be concerned.

The scheme represented in figure 8 comprises two a-c synchronous generators, G_1 and G_2, feeding a two-winding d-c motor (M) through a connection without appreciable resistance and through rectifier tubes R_1, R_2, each tube being equipped with control grids. Neglecting the voltage drop in the connections and in the rectifier, the generator, let us say, induces a voltage E somewhat higher than the back electromotive force of the motor. Energy will then flow from the generator to the motor if the grids are energized so that the anodes of the rectifiers are permitted to carry current. Let us assume that one electric valve, R_2, is blocked and therefore current will flow only through the left-hand winding of the motor, bringing it up to speed in the direction indicated by the heavy arrow. The motor will operate in this direction as long as current I_1 produced by generator G_1 can flow through R_1. At a certain instant of time the grids of rectifier valve R_1 are negatively energized by the auxiliary grid equipment, current I_1 is prevented from flowing, and the motor comes to a stop, see figure 8. However, at the same time the grids of R_2 are de-energized and since generator G_2 impresses a potential E_2, current I_2 will flow through the right-hand winding of motor M and bring this motor up to speed; however, in the opposite direction. It can therefore be seen that by impressing a negative potential on grids of rectifier R_1 and then on grids of rectifier R_2, this motor will reverse at a frequency equal to the frequency of the voltage applied to the grids of these two rectifier valves. The frequency of the reversal of motor M is independent of the frequency of generators G_1 and G_2—in other words, independent of the frequency of the voltage applied to the anodes of rectifiers R_1 and R_2. Further, it can be seen that the frequency of reversal of motor M is independent of the frequencies of generators G_1 and G_2 whether these generator frequencies are the same or not.

Let us now apply the above reasoning by following the circuit of figure 9, and we shall find that with a simple control device for energizing the grids, power of a 60-cycle frequency can be converted into

single-phase energy of 25-cycle frequency if the grids of the anodes of the left-hand unit and those of the right-hand unit are energized consecutively with potentials of opposite polarity. The reversal frequency of the grid potentials would have to be equal to the frequency of the single-phase output, namely, 25 cycles. In this arrangement, however, instead of a reversal of direction of rotation, a reversal of voltage on the primary of the single-phase transformer takes place, which is at the rate of 25 cycles if the grids are controlled from the single-phase 25-cycle network.

A more specific arrangement of the grid control is shown on the left-hand side of figure 9. The potential of the grids is controlled by three mechanical contacting devices m, m_1, and m_2, and is supplied by a battery. The devices m_1 and m_2 which are driven in synchronism with the frequency of the three-phase system therefore energize the grids at the same frequency as the anodes of each group, S_1 and S_2, of the rectifier-inverter. However, contactor m supplies the battery potential to each of the contactors m_1 and m_2, or, in turn, to each group of anodes S_1 and S_2, according to the speed of motor M_2. This motor, as can be seen, is driven from the 25-cycle system and, if of the synchronous type, will energize the grids of each group negatively through the battery and contactor segment m once during each revolution or, if a two-pole motor is used, at the frequency of 25 cycles. If the frequency of the single-phase system changes, then the speed of rotation of contactor m changes, and accordingly the interval during which the brush is in contact with the segment. The groups S_1 and S_2 may therefore furnish current for shorter or longer intervals which will be reflected in the frequency of the energy transferred to the single-phase system. Therefore, the frequency of the energy transferred to the primary winding of the single-phase transformer from the three-phase network follows the frequency of the impulses of the contactor m, and since this device is driven by a synchronous motor M_2, energized by the single-phase system, it follows the frequency changes of this system. A completely flexible coupling of the two systems is therefore effected.

The same results can be obtained by using electronic instead of mechanical control equipment, see figure 10. Comparing this with the mechanical control shown in figure 9, the circuit of the electronic control can easily be analyzed. A 12-anode rectifier with electrically controlled grids is connected to the secondary windings of a 60-cycle transformer. The energy-storing equipment comprises a reactor and a battery of capacitors. The control devices consist of grid-controlled tubes and 60- and 25-cycle auxiliary transformers.

Relative Advantages and Disadvantages of Different Methods of Frequency Changing

The discussion below will deal especially with the system shown in figure 10, or similar ones, and only touch lightly on other methods of frequency changing.

From the foregoing it could be seen that the system as shown in figure 2 with an intermediate d-c step does not make it possible for the three-phase network to take care of the reactive power of the single-phase trolley system. Synchronous or static condensers would have to be connected to the trolley system, see figure 2, or then the reactive power would have to be furnished by rotating converters connected in parallel with the electronic converters. Furthermore, in order to obtain successful operation, a reactor has to be connected into the d-c link for reasons given in the second section of this paper. This method, however, permits transferring energy in either direction and may show some additional advantages after more experience has been obtained with d-c transmission of power. Furthermore, this method provides a completely flexible link between the two systems, has a high conversion efficiency (since a high intermediate direct voltage can be chosen making the arc losses negligible), and possesses effective regulation and protective features by means of energized grids.

Such systems for conversion of three-phase power into direct current and back into another three-phase system have been operating in the United States and Europe for many years. These systems make use of intermediate direct voltages of 3,000, 15,000, and up to 48,000 volts, respectively.[11,21,23,27] Although these systems are three-phase to three-phase conversions, still they deserve careful study when considering new frequency-changing equipment for railroad electrification.

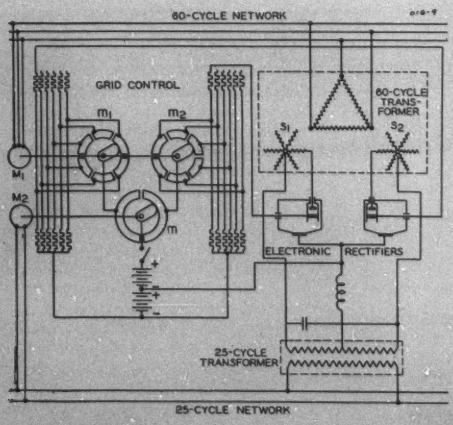

Figure 9. Circuit diagram of electronic frequency converter showing mechanical grid-control equipment

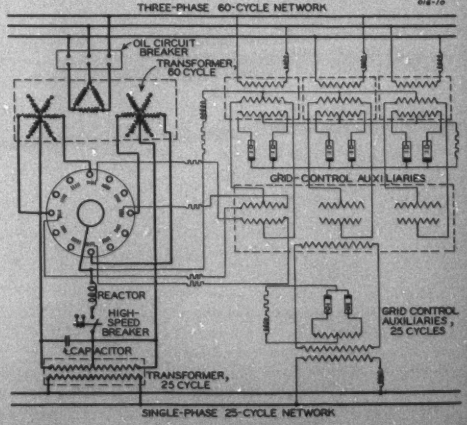

Figure 10. Circuit diagram of electronic frequency converter showing static electronic grid-control equipment

The direct-coupled system (no intermediate step), although it can be made flexible, did not receive much attention in the initial tests nor was such equipment installed on some of the European railway systems. The output voltage for the rectifiers is determined by the trolley voltage and will therefore be fairly high for all existing electrified $16^{2}/_{3}$- or 25-cycle lines, and the anodes of this rectifier as well as of the inverter are subjected to a high commutation voltage.

The indirect-coupled systems permit the selection of the most suitable rectifier-inverter voltage in order to utilize the anodes to the fullest degree as the single-phase transformer ratio can be chosen accordingly. Both methods, shown in figures 7 and 10, have been utilized and are therefore given further consideration below. The investigations were made based on a set for 5,000 kw, a power factor of 70 per cent, and conversion of power from 60 to 25 cycles at conventional alternating voltages. The rating of 5,000 kw for the electronic converter sets was chosen in order to be in line with the rating of the present single-phase feeder transformers as used on one of the main electrified lines. Both sets are static and permit the same ease of starting, and may therefore be applied in the same way in connection with electrified lines.

The rectifier-inverter tanks consist of several anodes equipped with energized grids and their necessary control devices. The first method of this kind, see figure 7, necessitates an abnormal number of anodes per tank and an exceedingly accurate control device. Furthermore, the transformer connections are quite abnormal and require a relatively complicated design. The other indirect-coupled system makes use of normal rectifier-inverter tanks with grids, a 60-cycle three-phase transformer with double six-phase secondary, and interphase transformers, both being of the same types as used in standard rectifier installations, and a 25-cycle transformer, single-phase with mid tap.

It can therefore be realized that this last-mentioned system deserves careful consideration. However, some of the main characteristics of both these indirect-coupled systems will be discussed below. Since most of these systems are flexible they have to be compared with motor generator sets which permit elastic coupling of two networks.

Voltage Regulation

From figure 11*a* it can be seen that the voltage regulation is similar to the regulation of a standard transformer. Curve 3 shows the regulation of a transformer, and

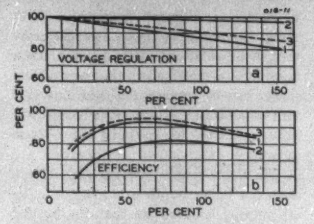

Figure 11. Performance characteristics of a typical electronic frequency converter of 5,000-kw rating compared with a transformer and flexible rotating converter of equal rating

curve 1 that of a 5,000-kw frequency changer, while curve 2 gives the voltage regulation of a motor generator set. It may be pointed out, however, that should this voltage drop, of about seven per cent at full load, be objectionable, a curve similar to number 2 could be obtained by means of additional grid-control devices, as shown in figure 10. This voltage regulation is naturally due to the drop in both of the transformers, in the reactors, and the arc drop of the rectifier-inverter. As pointed out above, the voltage of the intermediate system can be chosen independently of the voltage of the a-c systems, and therefore if chosen at 2,500 volts, for instance, the regulation due to the rectifier-inverter arc drop would only amount to about one per cent at 5,000-kw load.

It may be pointed out that the voltage regulation of such a frequency changer is not affected by fluctuations of frequency nor by the phase relation between the voltages of the two networks, as is the case, for instance, in a synchronous motor generator set.

Efficiency

Not only is the efficiency of such a set higher at full load compared to a motor generator set, but it becomes relatively higher at lower loads. From figure 11*b* the efficiency of such a unit, curve 1, can be compared with the efficiency of a motor generator set, curve 2, as well as with that of a transformer, curve 3. The arc drop of the rectifier-inverter is very low and therefore the efficiency of such a frequency changer is also practically the same as that of a transformer, which can couple two networks of different voltages, but naturally cannot couple two networks of different frequencies.

It may be mentioned here that efficiency measurements on some of the actual installations to which reference was made previously reached as high as 93 per cent at full load. Curve 2 refers to a motor generator set of a design which permits flexible coupling of the two systems.

Due to the fact that in the installations referred to above the load factor is relatively low, about 25 per cent, the average difference in efficiencies between the motor generator set and the rectifier-inverter amounts to about 15 per cent. In other words, the losses are reduced very appreciably by this new type of converter. This, as pointed out above, is mostly due to the fact that the efficiency of such a type of frequency changer maintains a very high value, even at low loads.

Power Factor

A certain amount of wattless power has to be supplied by an external source to a frequency changer of the electronic type. This is required for the magnetization of the transformers and partly also on account of the phase displacement existing between the voltage and the current in this type of equipment, especially if grid voltage control is employed. In case of a system as shown in figure 7, if the energy-storing equipment is omitted, the power factor would probably only amount to about 60 per cent. In other words, a very high component of wattless energy would have to be furnished from the a-c supply system. However, with an arrangement such as shown in figure 10, a power factor of as high as 95 per cent can be obtained. Analysis shows that economically it will be feasible to equip such a set with an energy-storing equipment. However, it may be pointed out that in case the capacitors should fail for any reason, the frequency changer would not be affected in its operation. However, it would then adversely affect the three-phase system, by drawing additional wattless power, and causing an unbalance of the three-phase system.

Protective Equipment

In all considerations referred to above, reference was made repeatedly to grid-control equipment in connection with regulating the valve action of the rectifier and inverter, as well as regulating the voltage. It may be pointed out, however, that the grids may be used for another purpose also, namely, to protect the equipment in case of abnormal operating conditions and disturbances on the line as well as short circuits and backfires.[25] Extensive tests in many installations have proved that the electrically energized grids are able to interrupt the current flow in a tank such as proposed for the above frequency-changer set. The equipment required for this purpose consists of relatively inexpensive devices which permit

energizing the grids of the inverter with a negative potential in case of sudden disturbances. Recent tests have shown that this time can be confined to less than one-sixth of a cycle. Naturally this equipment will not eliminate breakers completely but may make it possible to use switching devices of lower rating.

Feeder and Trolley Voltages

It can easily be realized that since any ratio between primary and secondary voltage on both transformers can be chosen, no additional equipment will be necessary in case the single-phase 25-cycle system would require a higher voltage than commonly used. In the case of a motor generator set, it would probably not be advisable to generate directly a voltage of 25,000 volts or higher, but instead a transformer could advantageously be connected between the single-phase generator and the trolley system.

Space Requirements

Present installations have shown that a considerable saving in space can be obtained with this type of frequency changer. Furthermore, the cost of foundations and building can be greatly reduced, similarly as in any mercury-arc-rectifier installation.

Flexibility of a Static Frequency-Changer Set

As pointed out repeatedly, a set as shown in figure 10 can operate without losing its stability even in case of severe frequency variations on either of the two systems, or during heavy load swings.

Telephone Interference

As mentioned in the introduction, the installation of one of these frequency changers caused relatively serious disturbances in the adjacent telephone lines. However, it must be realized that this installation was fed from a relatively small power source, and therefore the wave-shape distortions due to the rectifiers were transferred to the a-c networks without appreciable diminution. For large railway systems, where many units would be used, it may be possible to take care of this situation by establishing such phase relations between the different units that a multiple-phase system could be obtained, as was done in one of the largest rectifier plants recently installed in this country.[23]

Conclusion

It can thus be seen that there are several methods which permit coupling of networks of different frequencies with static electronic devices. The first system, using an intermediate d-c step, has a considerable drawback in that no wattless power can be transmitted from one system to another. However, it has proved very successful for coupling three-phase networks.

The direct-coupled system, although it does not have the above-mentioned disadvantage, necessitates that the output voltage of the rectifier-inverter be equal to the single-phase voltage and requires that single-anode rectifiers be used.

The indirect-coupled system, on the other hand, permits choosing any output voltage for the rectifier-inverter, allows the exchange of wattless power from one system to another, and permits full flexible coupling. The methods used in Europe, necessitate a 3:1 ratio between frequencies, and cannot be applied to the electrified railway systems in the United States where frequency conversion from 60 to 25 cycles, or a 2.4:1 ratio is necessary. However, the conversion of frequencies, as is necessary in this country, may subject the anodes of the rectifier-inverter to a more favorable load cycle than in case of the frequency ratios required in Europe.

In order to give a proper comparison between the characteristics of these converters of the electronic type with those of the rotating converters at present used, a rating of 5,000 kw was selected for ready reference.

It could be seen from the foregoing that the main advantages of an electronic frequency changer are high efficiency, very simple operation, no necessity for special starting equipment or high starting load, instantaneous starting up of the equipment, small weight of the equipment, especially of the control equipment, which reduces costs for housing and foundation.

The disadvantage of such converters, in so far as can be seen at present, is the distortion caused by them on the three-phase supply network, unless somewhat large and costly energy-storing devices are employed.

It may also be pointed out that the present installations referred to should make it possible to develop in the future frequency changers of this type for very large capacities which may also become a very useful means for the conversion of power for present electrified systems now using 60-to-25-cycle motor-generator converters.

Bibliography

1. On the Power Supply of Main Railroads From Three-Phase Systems, Doctor Wilhelm Wechmann. *Elektrische Bahnen*, volume 8, 1932, page 45.

2. Fundamental Phenomena of Rectifiers, Doctor Wilhelm Wechmann. *Elektrische Bahnen*, volume 8, 1932, page 46.

3. Technical Principles and Application of Rectifiers, R. Tröger. *Elektrische Bahnen*, volume 8, 1932, page 48.

4. Current and Voltages in Plants for Conversion of Three-Phase Alternating Current, 50 Cycles Per Second, to Single-Phase, 16⅔ Cycles Per Second, H. Meyer-Delius. *Elektrische Bahnen*, volume 8, 1932, page 59.

5. The Mutator Converter System Löbl./-R.W.E. for Traction Purposes, O. Löbl. *Elektrische Bahnen*, volume 8, 1932, page 65.

6. A Direct-Step as Synchronous Frequency Changer for Low-Frequency Railway Systems, Dr.-Ing. Schenkel, e.h.M. *Elektrische Bahnen*, volume 8, 1932, page 69.

7. A Flexible-Coupling Frequency Changer With No Distortion of the Primary Current, H. Meyer-Delius. *VDE-Fachberichte*, 1934, page 111.

8. The 4,000-Kva Mutator Frequency-Converter for the Basel Substation of the Wiesenthal Section of the German State Railway, R. Tröger. *Elektrische Bahnen*, 1934, volume 10, page 15.

9. Static Converter With Current and Voltage Smoothers for Flexible Coupling a Three-Phase 50-Cycle Network With a Single-Phase 16⅔-Cycle Network, C. Ehrensperger. *Brown Boveri Review*, June 1934, page 95.

10. The Flexible Coupling of Independent Three-Phase Networks by Means of a Single Mutator, E. Kern. *Brown Boveri Review*, December 1934, page 214.

11. Three-Phase to D-C Substations of the Italian State Railways Using Brown Boveri Inverters, A. Greco. *Brown Boveri Mitteilungen*, 1934, page 222.

12. Flexible Coupling of Electric Systems by Means of Three-Phase/Single-Phase Mutators, A. Darz. *Brown Boveri Mitteilungen*, December 1934, page 236.

13. Grid-Controlled Rectifiers and Inverters, C. C. Herskind. Electrical Engineering (AIEE Transactions), June 1934, page 926.

14. Voltage Control of Vapor Rectifiers, D. Journeaux. Electrical Engineering (AIEE Transactions), June 1934, page 976.

15. The Primary Nonproductive Loading in Frequency Conversion of Three-Phase Power by Means of a Rectifier, Dr.-Ing. R. Feinberg. *Elektrische Bahnen*, volume 11, June 1935, page 151.

16. Connection and Control of Direct-Step Frequency Converters, Kettner and Reinhardt. *ETZ*, 1935, page 829, 861.

17. Installation, Performance, and Economy of the Mutator Frequency-Converter Plant at Basel, J. Schmitt and Doctor Kilb. *Elektrische Bahnen*, volume 13, 1937, page 191.

18. Performance of the Mutator Frequency-Converter, R. Reinhardt. *Elektrische Bahnen*, volume 13, 1937, page 203.

19. The Harmonics of the Mutator Frequency-Converter Plant at Basel, and Means for Their Reduction, H. Geise. *Elektrische Bahnen*, volume 13, 1937, page 208.

20. Experiments With the Mutator Frequency-Converter Plant at Basel, Heavy-Current Measurements, G. Wilke. *Elektrische Bahnen*, volume 13, 1937, page 215.

21. Rectifier Tests Point to D-C Transmission, O. K. Marti. *Electrical World*, July 4, 1936.

22. Wave Shape of 30- and 60-Phase Rectifier Groups, Marti and Taylor. AIEE Transactions, volume 59, 1940 (April section), pages 218–24.

23. The First 50,000-Volt Direct-Current Power Transmission by Means of Mutators, Paul Egloff. *BBC Review*, April/May 1939, page 92.

24. The Flexible Coupling of Systems, by Means of Mutators, Restores His Independence to the Station Operator, While Increasing the Economical Operation of the Systems.

Circuit Interruption by Air Blast

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Synopsis: By using the prestored energy of compressed air for the twofold function of circuit interruption and circuit-breaker operation, a new and original oilless circuit interrupter has been evolved. This air-blast circuit breaker has a guillotine-like arc-interrupting characteristic and can be made practically immune to the adverse effects of circuit recovery voltage.

The historical background of oilless circuit breakers is discussed with particular reference to European designs. The electrical and mechanical design of air-blast circuit breakers for indoor use and the factors affecting that design, are described in some detail.

IN VIEW of the desire to eliminate oil in electrical apparatus evidenced by the electrical power industry, research activities conducted during the past decade have been directed toward the development of a satisfactory current-interrupting principle, not involving the use of oil, but capable of application over the same ranges of current, voltage, and interrupting-capacity steps as the oil circuit breaker.

Fundamental Requirements

It has been recognized that to be acceptable to American power engineers, it is essential that any oilless circuit breaker must be compact, simple in operation, reliable, economical, and easily adaptable to the various forms of circuit connection and mounting at present obtaining for the oil circuit breaker. In addition, the desirability of obtaining an increase in interrupting efficiency has been recognized.

Development of Air-Blast Breaker

It is economically advisable and expedient that American manufacturers should avail themselves wherever possible of the operating experience and evolutionary test data appertaining to successful European designs, for, by so doing, much development time and expense can be eliminated, resulting in ultimate savings to the user. This procedure has been followed in the case of the air-blast breaker here described, thereby resulting in an initial American design from which outstanding reliability of operation has been obtained. A typical indoor air-blast circuit breaker of American manufacture is shown in figure 1.

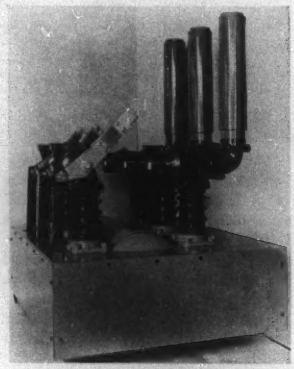

Figure 1. Type AB indoor air-blast circuit breaker, 1,200 amperes, 15,000 volts, 500,000-kva interrupting capacity having active operating parts enclosed

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European air-blast circuit breakers, of both axial and cross-blast designs, have been found to be subject to certain limitations so far as their ability to interrupt high currents is concerned. In addition, these limitations are aggravated when high rates of recovery voltage obtain.

In view of the mechanical advantages and operating experience of a certain European design, it was thought desirable to so improve the design of the interrupting chamber as to increase the maximum interrupting current ability of the breaker to the point where it would be adequate for use on American power systems. To this end, considerable laboratory research was conducted.

In the typical European type of axial air-blast breaker interrupting chamber, the compressed air approaches an orifice through a converging port, and exhausts through a diverging throat. In many European designs, too, the interrupting contact is a part of the isolating contact. This arrangement makes for inefficiency of the interrupting air blast as will be shown later in the paper.

As the result of extensive research, it was found that the arrangement of interrupting chamber shown in figure 2 has a greater interrupting efficiency, particularly at high currents, than the European type of converging-diverging chamber.

It will be noted from figure 2 that the American development incorporates a structure having parallel walls. Redesign of the cooling chamber to obtain increased air velocity, and the introduction of concentric metallic cylinders within the arcing chamber, produced further improvement. Main current-carrying contacts, as distinct from the arcing contacts, were also added.

Operating Characteristics

The design here described capitalizes on the mechanical operating experience and reliability of the European design and, using the prestored energy of compressed air for both circuit-breaker operation and circuit interruption, produces a practically constant circuit-interrupting characteristic, with the result that arcing times of one-half cycle or less are consistently produced throughout the interrupting range of any particular breaker, as shown in figure 3. The typical interrupting test oscillogram, shown in figure 4, shows the short arcing time obtained with this design.

As a consequence of the short arcing time, contact burning is very low and many repetitive operations can be made without contact renewal.

C. Ehrensperger. *BBC Review*, April/May 1930, page 117.

25. RECTIFIERS IN REVERSE, D. Journeaux. *Allis-Chalmers Electrical Review*, September 1939, page 20.

26. A MERCURY-ARC STATIC INVERTER, S. R. Durand. *Allis-Chalmers Electrical Review*, September 1939, page 25.

27. CONSTANT-CURRENT D-C TRANSMISSION, Willis, Bedford, and Elder. ELECTRICAL ENGINEERING (AIEE TRANSACTIONS), January 1935, pages 103-08.

28. GRID CONTROL OF RADIO RECTIFIERS, S. R. Durand and O. Keller. IRE *Proceedings*, volume 25, May 1937, page 570.

Discussion

Discussion will be found in the 1940 annual TRANSACTIONS volume and in the 1940 "Transactions Supplement" to ELECTRICAL ENGINEERING.

It has also been found that the interrupting action can be so controlled as to be independent of system characteristics, since it is possible to control the rate of rise of recovery voltage across the interrupting contacts immediately following arc interruption by means of the automatic insertion of resistors which prevent the occurrence of high-frequency transients and reduce the instantaneous values of generator electromotive force appearing at the moment of arc interruption.

Axial-Blast Application

Tests have proved that when using an axial-blast form of interrupting chamber, there is an optimum distance of break between the arcing contacts which produces a maximum interrupting effect. Figure 5 shows the relationship between megavolt-amperes interrupted and arcing-contact separation, with air pressure and port area constant. Obviously, it is desirable that in any air-blast circuit-breaker design, the arcing contact separation should be that which provides maximum interrupting efficiency.

Separation of Interrupting and Isolating Functions

It is evident that, since in indoor air-blast circuit breakers the maximum interrupting efficiency is achieved with a short arcing-contact separation of only one-half inch, considerations of circuit isolation require a co-operating disconnecting means. This necessitates an initial arcing contact break sufficient for the maximum interrupting efficiency, immediately followed by an appropriate isolation break, in series, opening under no-load conditions.

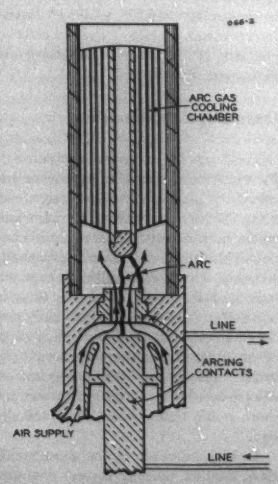


Figure 2. Typical air-blast interrupting chamber—American design

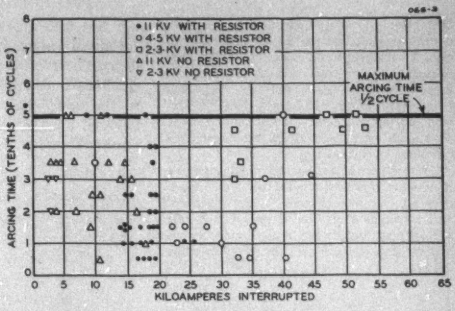


Figure 3. Graphical representation of interrupting-test data showing arcing time in tenths of cycles

The use of an independent interrupting contact also permits a very speedy opening of the arcing contacts during interruption, since the inertia of these contacts is relatively negligible when compared with the energy available in the compressed air. The isolating means takes the form of a disconnect switch, and is operated by the same pneumatic energy that opens the interrupting contacts and interrupts the circuit.

Compressed air used for operation of the contacts constitutes a pneumatic co-ordinating device which acts as a positively functioning mechanical interlock of unlimited flexibility. The relative diameter and volume of the operating devices, and of the air ducts leading to them, provide a superior timing means with which to insure proper sequential operation.

Closing Capabilities

Completion of the circuit through the breaker during closing, is achieved by means of the closing of the disconnecting or isolating contacts only, since, except during the interrupting process, the arcing contacts are held closed by the action of heavy springs.

Actual contact, during closing, is made between the movable disconnecting or isolating blade contact and a laminated wedge-type stationary contact. Burning, during closing, is very slight. Even when closing against currents of 140,000 rms amperes and above, there were only slight evidences of scorching or pitting.

The reason for the low contact-burning characteristics of the air-blast breaker during closing is in the very high speed of closing obtained. In order to burn a given quantity of contact material a definite amount of energy is required. Since time is a factor in the energy equation, and since, due to the high closing speed, the period of arcing during closing is extremely short, the breaker can be closed against very high currents without appreciable damaging effects, and with practically no heating or pitting of the contacts. It is especially to be noted that no blast of air on the contacts is required during the closing operation.

Separation of the interrupting and closing functions between two sets of contacts divides the contact deterioration consequent upon these functions; thereby lengthening the over-all contact life of the breaker.

Trip-Free Interrupting Contacts

As in the air-blast breaker the interrupting contact is free to move independently of, but co-operatively with the isolating or disconnecting means, it is essentially trip free in its position and relation to the disconnecting contacts. This fact is of great advantage, especially in the higher-voltage outdoor breakers where extremely rapid interrupting and reclosing times are required.

Breaker Arrangement

A typical design of indoor air-blast breaker is illustrated in figures 6 and 7. A compressed air tank (1), fitted with a main air blast valve (2), forms the foundation on which the active parts of the breaker are mounted. The arcing chambers (3) and disconnect movable members (5) are supported by hollow insulator columns attached to the tank assembly. The arcing chambers exhaust into cylindrical mufflers. Operation of the disconnects is achieved through insulated link (6) and shaft (7), connected to air pistons (8) and (9). Valves (10) and (11) control the air supply.

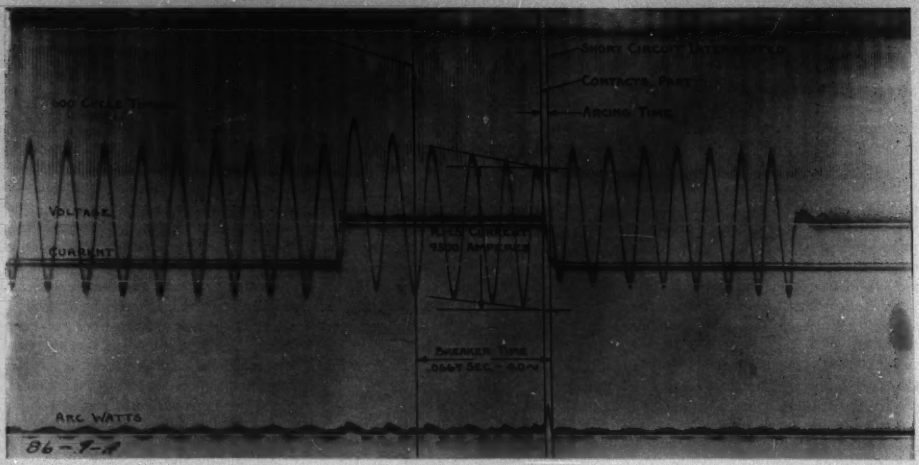


Figure 4. Type AB air-blast-circuit-breaker interrupting-test oscillogram

CO operation at 192,000 kva at 11 kv interrupted by a breaker having a 250,000-kva interrupting rating

Operation

Opening

When opening, electrical or manual actuation of control valve (11) results in opening of the air-blast valve (2), admitting air at 135 pounds or 215 pounds per square inch gauge pressure into the interrupting chambers.

Movable arcing contact (14), normally held closed by the action of heavy springs, is attached to a piston. As air pressure builds up within the interrupting chamber, the piston is depressed, withdrawing contact (14) the required distance away from the stationary arcing contact and air-blast orifice (13), drawing an arc between the contacts. As the tubular stationary contact is the only outlet for the compressed air, a blast of high-velocity air is simultaneously impelled across the initial arcing zone, resulting in limitation of arc-energy release and preventing reignition after the first current zero.

Simultaneously with the admission of air to the interrupting chamber, air pressure is applied to piston (9) resulting in opening of the disconnect contacts (5), under no load, as soon as arc interruption is complete.

Immediately the disconnecting contacts open, an auxiliary contact interrupts the circuit to valve (11), closing the valve. This cuts off the air supply to valve (2) and permits the air remaining on the reverse side of this valve to escape. The main valve then closes under the influence of a heavy spring and the pressure of air remaining in the tank; pressure in the arcing chamber falls and results in reclosing of the arcing contact due to spring pressure.

The air required for arc interruption causes pressure in the breaker air tank to fall. Since the tank is permanently connected to a compressed air storage system, the supply of air within the tank is quickly replenished.

Closing

When closing, electrical or manual actuation of control valve (10) causes compressed air to be admitted to the closing cylinder (8), resulting in the closing of the disconnecting switches. As the arcing contacts are already held closed, the closing of the disconnecting switches completes the circuit.

A simple mechanical interlock insures that all switching operations, once initiated, will be carried to completion. A mechanical trip-free device permits immediate reopening of the disconnecting switches in the event of their being closed against short circuits, even though air pressure may still be exerted upon closing piston (8).

Reliability of Operation

The successful air-blast breaker has to be more than an interrupting device. It must have adequate insulation, and must be able to carry its rated current continuously without exceeding prescribed temperature limitations. Also, like all circuit breakers, it must be capable of operating many times a day without failure of mechanical parts, and yet, on the other hand, be capable of operating satisfactorily after having stood for a period of time without being operated. Several years of experience in the manufacture and operation of

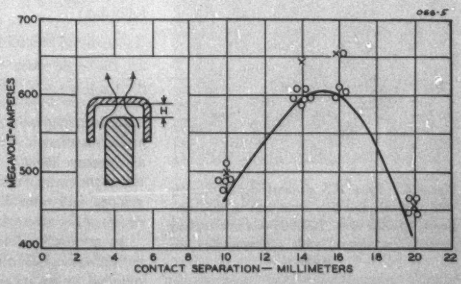


Figure 5. Relation between interrupting-contact separation and interrupting ability in megavolt-amperes

Circles—Effective interruption
Crosses—Interruption with remnant arc (Air pressure and port area constant)

air-blast circuit breakers have provided knowledge of the proper materials to use in mechanical parts, such as pistons, valves, valve seats, piping, and interlocks; giving assurance that the breaker can accomplish repetitive operations, as well as function satisfactorily, when infrequently operated.

Apart from the two solenoid control valves for closing and tripping the breakers, there is only one valve which must seal against the air pressure. This is the main air-blast valve, which is a simple composition valve, easily accessible. The method of mounting this main air-blast valve is such that the air pressure in the storage tank acts on the valve to secure tightness.

General Factors Affecting Design

The most efficient circuit breaker is the one in which, all other things being equal,

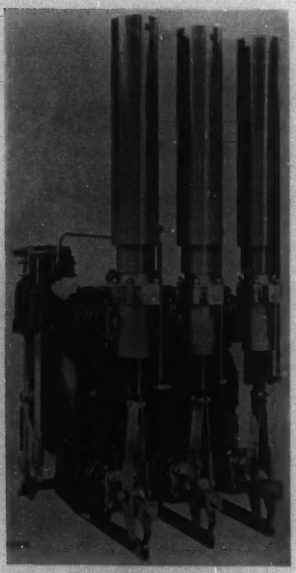


Figure 6. Type AB air-blast circuit breaker with vertical mounting arrangement, 600 amperes, 15,000 volts, 500,000-kva interrupting capacity—equipped with arc-paralleling resistors

the rate of dielectric recovery between the arcing contacts, immediately following the first passage of the current wave through zero, after parting of the contacts, is always greater than the rate of recovery voltage rise across the contacts. Under these circumstances, restriking of the arc is impossible and the maximum period of arcing is one-half cycle.

In designing a circuit breaker, there are two lines of attack by which maximum interrupting efficiency may be obtained. First, by the production of a high rate of dielectric recovery and second, by limiting the rate of rise of the recovery voltage. These two factors are used in the design of air-blast circuit breakers with such marked success as consistently to produce arcing times of one-half cycle or less.

Tests have proved that there are four factors which influence the interrupting capacity of high-voltage air-blast circuit breakers. These are:

1. Air pressure
2. Port area
3. Series breaks
4. Automatic insertion of resistors

The first three of these factors contribute toward control of dielectric recovery. The fourth factor produces a measure of control over the rate of rise of recovery voltage. The proper correlation of such of these factors as may be required produces air-blast circuit breakers of almost any desired interrupting capacity in the sizes usually required. This holds true for a wide range of interrupting capacities and for all standard voltage ratings up to and including 220,000 volts.

Factors Affecting Dielectric Recovery

Air Pressure

Dielectric recovery between the arcing contacts of air blast breakers is assisted by three different air-pressure characteristics. These characteristics result in the following:

1. Dynamic effect
2. Dielectric effect
3. Cooling effect

Dynamic Effect. Initial opening of the arcing contacts is effected by means of the air pressure itself. An arc is drawn between the contacts, but is immediately enveloped and centralized by the dynamic action of the air under high pressure.

An arc may be visualized as an incandescent core of concentrated electrons surrounded by an incandescent envelope of ionized gas. Due to the dynamic effect of the compressed air, the arc is centralized and its length controlled. This contributes toward limitation of arc energy release.

During the process of arc extinction the air pressure rapidly forces the arc products and any ionized gas into an arc gas cooling chamber, and so produces extremely rapid scavenging and deionization of the arc path.

Dielectric Effect. That the dielectric value of air increases due to compression, is well known. When under a pressure of about 135 pounds per square inch, the dielectric value of air is approximately equivalent to that of high-grade oil. Due to the passage of this high-dielectric medium between the contacts an inherently rapid build-up of dielectric is obtained.

Cooling Effect. The compressed air usually employed, is under a pressure of either 135 pounds or 200 pounds gauge per square inch. It is obvious that the sudden release of such pressures in the arc zone, and the instantaneous expansion of the air, will create intense cooling action.

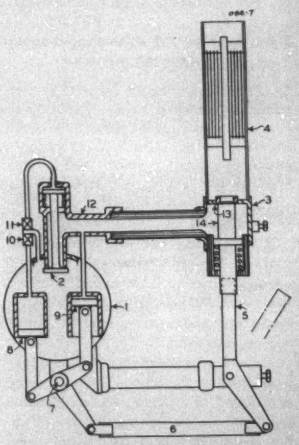


Figure 7. Typical type AB air-blast-circuit-breaker pole section

The cooling action deionizes the arc and limits its conducting ability by reducing its cross section.

Due to the inherent characteristics of an a-c system, the cross section of the arc diminishes as the current approaches zero. This causes an increase in the relative cooling effect of the air blast immediately before current zero.

Total Effect of Air Pressure. The combination of a high-velocity high-dielectric cooling medium produces the maximum interrupting effect and is responsible for the short interrupting time of one-half cycle or less, experienced with most air-blast breakers.

Due to the short arcing time, and the low release of arc energy, contact burning is greatly reduced. Consequently, long contact life is obtained, even when interrupting high currents. Many thousands of interruptions are obtainable without the necessity of contact renewal.

Many interrupting tests with varying short-circuit currents, and at different air pressures, have proved that a definite relation exists between interrupting capacity and air pressure. As shown in figure 8, the increase in interrupting capacity is almost proportional to the increase in pressure.

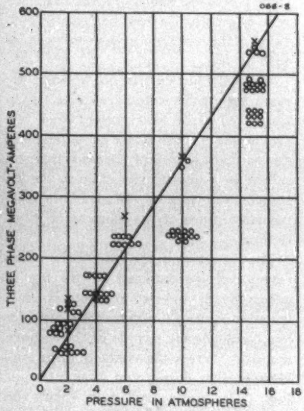


Figure 8. Relation between air pressure and interrupting ability in megavolt-amperes

Circles—Effective operations
Crosses—Ineffective operations
(Port area constant)

Port Area

Since a definite control is obtained by means of the dynamic, dielectric, and cooling effects of the air blast, it follows that these effects will be increased if the volume of air made available is increased, provided that the air pressure remains constant.

By increasing the area of the port, increased interrupting capacity is obtained as shown in figure 9. The proportional relationship between the area of the port and the interrupting capacity there shown has been verified by a large number of tests.

Series Breaks

As the recovery of dielectric between the arcing contacts depends more or less directly on the pressure of the air, it follows that, provided air pressure remains constant, an increased measure of dielectric recovery should be obtainable by connecting a number of breaks in series.

Tests have proved that while an improvement in interrupting capacity can be obtained by the use of series breaks, the increase in capacity is not in direct proportion to the increase in the number of breaks as is shown in figure 10.

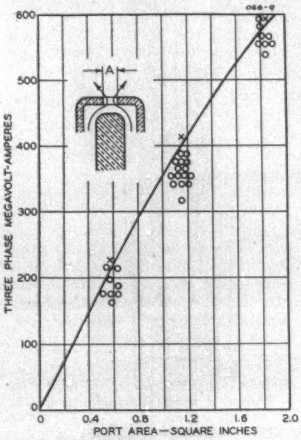


Figure 9. Relation between port area (orifice) and interrupting ability in megavolt-amperes

Circles—Effective operations
Crosses—Ineffective operations
(Air pressure constant)

There are practical limitations to the use of series breaks. Mechanical design factors, insulation difficulties, and costs increase with each additional break. It is also obvious that the expenditure of air must increase with each additional break.

The electrostatic relations which cause unequal voltage distribution across series breaks, increase with the number of breaks. In the case of the indoor air-blast breakers here described, one break per phase is sufficient in all cases.

Factors Affecting Rate of Rise of Recovery Voltage

Insertion of Resistors

On circuits where the impedance consists largely of reactance, the power factor at the moment of arc interruption may be low. Due to the lower power factor, current zero occurs at a time when the generator electromotive force would normally be in the vicinity of its crest value, so that, at the moment of interruption, the voltage across the contacts rises rapidly to a value corresponding to the generator electromotive force.

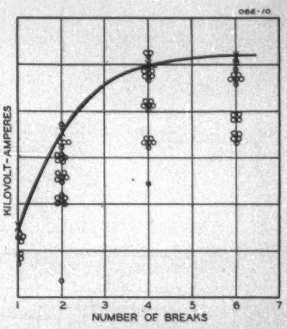


Figure 10. Relation between number of breaks in series and kilovolt-amperes interrupted

Circles—Effective operations
Crosses—Ineffective operations
(Air pressure and port area constant)

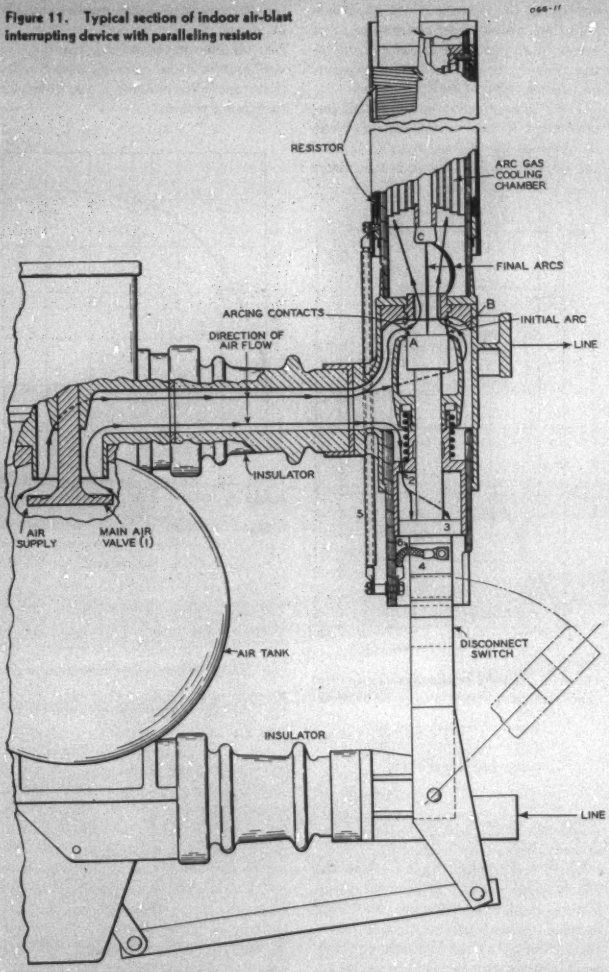
The rate at which the voltage rises is affected by the characteristics of the circuit under interruption, and also is dependent upon the instantaneous value of the generator electromotive force at current zero.

Upon interruption of the short circuit, the stored energy in the system tends to discharge, since a-c circuits are composed of both inductance and capacitance. The well-known inductive kick from coils of many turns, such as field coils, illustrates one type of circuit discharge. The snapping discharge of a capacitor illustrates another. An interruption on a large power system may produce both of these kicks in magnified form, and in an infinite variety of phase relations.

When the generator electromotive force re-establishes itself, immediately upon interruption of the short circuit, the inductive and capacitive discharge effects are superimposed upon the characteristic form of the normal-frequency electromotive force in the form of a high-frequency transient which may rise to a value as much as twice or more the instantaneous value of the generator electromotive force. This transient is usually a combination of various frequencies which depend upon the natural frequency of different circuit combinations obtainable in the system interrupted.

The rate of rise of the combined recov-

Figure 11. Typical section of indoor air-blast interrupting device with paralleling resistor



ery voltage depends upon the instantaneous value of the generator electromotive force, the amplitude of the superimposed transient, and upon the frequency of the transient.

It has long been known that the rate of rise of recovery voltage can be beneficially influenced by inserting a resistor into the interrupting circuit. In the air-blast breaker limitation of the rate of recovery voltage rise is accomplished by the use of resistors inserted into the circuit by means of the action of the arc itself.

Indoor air-blast circuit breakers having 150,000-kva interrupting rating and higher are usually equipped with paralleling resistors. The method of connecting and mounting the resistor is shown in figure 11. It will be seen that the resistor is noninductively wound around the muffler housing.

As the arcing contacts *A* and *B* separate, an arc is drawn between them and the centralizing action of the air-blast forces the arc into contact with the probing electrode *C*, thereby automatically inserting the resistor in parallel with a portion of the arc during the first half cycle of arc.

As the fault current decreases after reaching its maximum value during the first half cycle, the resistance of the arc increases rapidly, so that the current tends to follow the alternative path from (4) through the resistor in series with the section of the arc from the electrode *C* to the stationary arcing contact *B*. The section of the arc between the moving contact and the electrode then becomes unstable and goes out.

The section of the arc between the electrode *C* and the stationary contact *B* is momentarily maintained after the main arc from the moving contact *A* to the electrode *C* is extinguished, but the fault current is greatly limited due to the high value of the resistance connected in series with the arc.

When the low-current arc between the electrode and the stationary contact is extinguished at or near current zero, improvement in power factor has taken place due to the insertion of the resistance, resulting in a marked reduction in the instantaneous value of the generator electromotive force at the moment of interruption.

The reduction in the rate of rise of recovery voltage obtained by the use of automatically inserted resistors is illustrated in figure 12, which shows cathode-ray oscillographic records of the voltage appearing across the contacts of an air-blast breaker during and after interruption. The upper oscillogram shows the voltage condition when no resistor was used and the lower oscillogram shows the improvement obtained by the use of resistors.

It is apparent that the rate of rise and the maximum value of recovery voltage is much less when an automatically inserted resistor is used. High-frequency transients are practically eliminated and the voltage immediately following arc interruption, follows generally the normal sinusoidal wave form. A representative oscillogram of an interrupting test made on an air-blast breaker equipped with resistors is shown in figure 13.

Summary

It is evident from the foregoing description that the air-blast breaker has several very desirable characteristics.

1. It is an oilless breaker.
2. It can be applied over practically the same range of interrupting-capacity steps and voltages as the oil circuit breaker, both indoor and outdoor.
3. The prestored energy of compressed air is used, not only for circuit interruption but also for opening and closing contacts, and for proper sequential timing.

4. Its current-interrupting range is such as to meet the maximum interrupting-current requirements on each interrupting step.

5. It gives control over the magnitude and rate of recovery voltage rise.

6. Short arcing time permits fast interrupting time.

7. Separation of interrupting and isolating contacts enables fast reclosing.

Conclusion

The air-blast breaker is a scientific product which is a direct result of the availability of high-power circuit-breaker testing laboratories. Its performance under all kinds of conditions, has been checked and rechecked; its operating characteristics and limitations have been determined; and operating security has been assured by the application of adequate safety factors and interlocks.

As a result of the extensive research conducted during the evolutionary process, it is possible to predetermine the performance of this air blast circuit breaker by means of a judicious combination of air pressure, port area, series breaks, and arc paralleling resistors. And so there emerges from the testing laboratory, a unique oilless circuit breaker of simple, sturdy and compact design, which is applicable to practically all current, voltage, and interrupting ratings. Comprehensive and reliable test data enable its adaptation to almost any particular set of system characteristics within its rating, and prove its ability to render satisfactory service under the most arduous demands of American power systems.

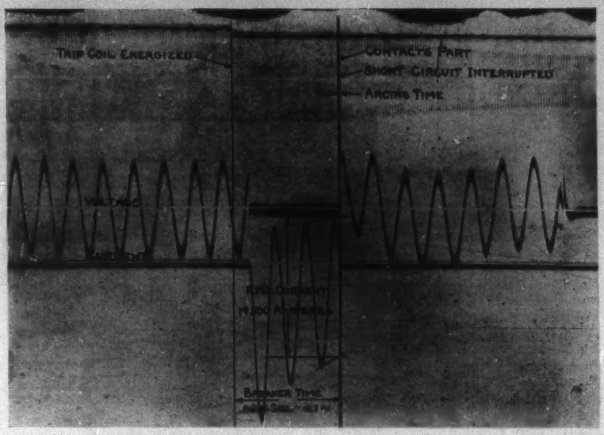


Figure 13. Oscillographic record of interrupting test of a 1,200-ampere 15-kv 500,000-kva interrupting capacity air-blast circuit breaker, when interrupting 429,000 kva at 11 kv. Arcing time 1/600 (0.00167) second

Acknowledgment

During the successful development of the air-blast circuit breaker, reliance has been placed on the co-operative efforts of many individuals. Acknowledgment is here made of valuable contributions from the staffs of the circuit-breaker testing laboratories and engineering departments of the Allis-Chalmers Manufacturing Company and of the Brown Boveri Company.

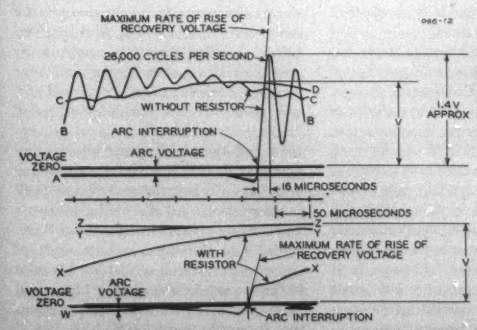


Figure 12. Cathode-ray oscillogram showing prevention, by resistor, of high-frequency transients

Upper section, without resistor, shows transient with frequency of 26,000 cycles. Record starts at *A*, continues to *B*, reappears at *B* (left), continues to *C*, reappears at *C* (left), terminates at *D*. Arc voltage decreased to zero from peak value at interruption point. High-frequency transient appeared; voltage reaching 1.4 times normal maximum sinusoidal value in the short time of 15 microseconds. Oscillations gradually decrease to *D*

Lower section, with resistor, record starts at *W*. Resistor limited voltage peak before arc interruption. Rate of recovery voltage rise greatly reduced after interruption. Voltage-wave rise rate tapered off, following approximately sinusoidal form through *X* and *Y* to *Z*. Maximum voltage value not reached until 750 microseconds

References

1. Air-Blast Circuit Breakers, **W. S. Edsall.** *Allis-Chalmers Electrical Review*, March 1939.

2. A Typical European High-Speed Air-Blast Circuit Breaker, **W. S. Edsall.** *Allis-Chalmers Electrical Review*, December 1939.

3. Air-Blast Breakers Control Recovery Volts, **G. E. Jansson** and **H. W. Martin.** *Electrical World*, July 29, 1939.

4. Der Druckluftschalter und die Bedeutung seiner kurzen Ausschaltzeit für den Netzschutz, **H. Thommen.** S.E.V. Bern, November 26, 1938.

5. Arc Extinction Phenomena in High-Voltage Circuit Breakers Studied With a Cathode-Ray Oscillograph, **R. C. Van Sickle** and **W. E. Berkey.** AIEE Transactions, 1933.

6. Influence of Resistance on Switching Transients, **R. C. Van Sickle.** AIEE Transactions, volume 58, 1939 (August section).

7. Effect of Restriking on Recovery Voltage, **C. Concordia** and **W. F. Skeats.** AIEE Transactions, volume 58, 1939 (August section).

8. The Brown Boveri Air-Blast High-Speed Circuit Breaker and Its Importance for the Protection of Networks, **R. M. Wild** and **J. Schneider.** *Brown Boveri Review*, April/May 1939.

9. Le Disjoncteur "Auto Pneumatique", **Charles Bresson.** *Bulletin* de la Société Française des Électriciens, July 1938.

10. The Electric Strength of Air at High Pressure, **H. H. Skilling.** AIEE Transactions, volume 58, 1939 (April section).

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

The Cross-Air-Blast Circuit Breaker

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NONMEMBER AIEE

Synopsis: The designs of European air-blast circuit breakers are not wholly satisfactory for operation in the United States as they do not handle high enough currents, cannot economically be built for high enough interrupting capacities, and do not conform to United States installation arrangements.

Accordingly, a new type of air cross-blast circuit breaker has been developed which does conform to the above requirements. The commercial design of this circuit breaker is discussed in a companion paper "Design and Construction of High-Capacity Air-Blast Circuit Breakers" by Messrs. H. E. Strang and A. C. Boisseau, and the present paper analyzes the theory of performance of the foreign and cross-blast circuit breakers, and presents evidence from a number of sources which throw light on the method of operation. The circuit breaker is found to operate predominately on the displacement theory. The nature of its performance makes it much less sensitive to recovery rate and high currents and much more economical in air consumption than air-blast breakers previously available.

FOR a number of years air-blast circuit breakers have been built in Europe. These designs have been watched closely; individual breakers have been imported and tested. An air-blast circuit breaker of purely domestic design is now being put upon the market. This circuit breaker is described in a companion paper by Messrs. H. E. Strang and A. C. Boisseau (*Transactions pages 522-7*).

Inasmuch as this design differs completely from foreign practice, it is interesting to examine the reasons for this pronounced difference, and the inner workings of the new device. Figure 1 shows diagrammatically the typical Continental design, which may, for the sake of identification, be described as radial blast. It consists of a male contact and a segmental female contact through which air is discharged when the circuit breaker is opened. The air stream envelopes the male contact on its way to the nozzle. It thus tends to cool the arc and blow the arc products away from the male contact and out through the nozzle. Due to the fact that the arc is extinguished by an independent source of power, the air blast, the performance of such a circuit breaker is

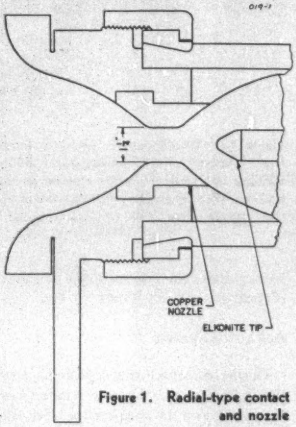

Figure 1. Radial-type contact and nozzle

highly reproducible and it is an excellent design for analytical study.

A considerable number of tests has been made on nozzles corresponding approximately to the Continental designs. Figures 2*a*, *b*, and *c* give the results of such tests. In figure 2*a*, it is shown that with voltage recovery rate and air pressure constant, the current-interrupting capacity is proportional to nozzle diameter. In figure 2*b* it is shown that with voltage recovery rate and nozzle diameter constant, the current interrupted is proportional to air pressure. In figure 2*c*, it is shown that with pressure and nozzle diameter constant, current-interrupting capacity is inversely proportional to recovery voltage rate between limits. This inverse proportionality fails at high currents, therefore, there is a maximum current which can be cleared no matter how low the rate of rise of recovery voltage may be. The design of figure 2*c* corresponds to a Continental rating of 400,000 kva at 10 kv or 23,000 amperes. Examination of the figure shows that at this rating the recovery rate must be quite low, 150 volts per microsecond at 120 pounds per square inch and about 500 volts per microsecond at the breaker's rated pressure, as compared with a figure of 1,800 for the usual testing station. It further appears that the kilovolt-ampere rating must be sharply reduced if the operating voltage is below 8,000 volts no matter how low the recovery voltage may be.

Since United States circuit-breaker standards call for interrupting current ratings as high as 60,000 amperes for a 250,000-kva circuit breaker, it is apparent that the Continental design would have to have a much smaller rating if it were to be applied in any standard manner in this country. Since the nozzle diameter increases as the first power of the current to be interrupted, while the air requirement goes up as the square of the nozzle diameter, the larger nozzle required to meet United States conditions would have a very greatly increased air consumption and would not be an economical design. A satisfactory design for the United States should be able to handle considerably higher recovery rates and at the same time should be able to handle maximum currents with a minimum of air consumption.

Accordingly the cross-blast design described in the Strang-Boisseau paper has been evolved. Figure 3 is a cross section of the interrupting unit. This consists of a pair of contacts located in an arc chute of insulating material. Air is introduced at one side of this chute. The air velocity is, therefore, at right angles to the arc stream and blows the arc against a number of barriers also of insulating material. In effect the arc is caught in the grip of a multiple shear having a movable member consisting of jets of air and stationary members of insulating material. At current zero the arc is cut up into sections and the arc products blown away (through the arc chute) into a muffling structure. This structure lends itself well to observation. All of the usual magnetic and cathode-ray measurements can be recorded and the chute can be made of transparent material so that the behavior of the arc can be observed by high speed photography. The usual high speed cameras operating up to 2,000-3,000 frames per second do not provide enough observations close to current zero. However, a special camera was developed which is capable of a maximum speed of 120,000 frames per second.[13] Since the arc phenomena in the cross-blast chute last for periods between a half and one cycle, the camera was slowed down so as to take 60,000 frames per second, that is, its total of

Paper 40-19, recommended by the AIEE committee on protective devices, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 13, 1939; made available for preprinting December 12, 1939; released for final publication March 27, 1940.

D. C. PRINCE, manager of the commercial engineering department, General Electric Company, Schenectady, N. Y., was chief engineer of the switchgear department of the company at Philadelphia, Pa., at the time the paper was presented; J. A. HENLEY is with Metropolitan Vickers Company, Ltd., Manchester, England, and W. K. RANKIN is with the General Electric Company, Philadelphia, Pa.

13. For all numbered references, see list at end of paper.

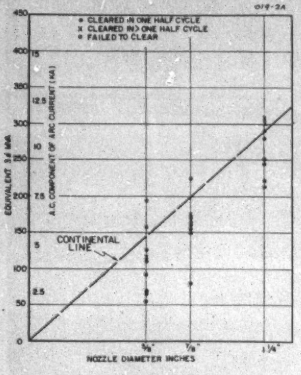

Figure 2a. Variation of rupturing capacity with nozzle diameter at 120 pounds per square inch, radial-type nozzle

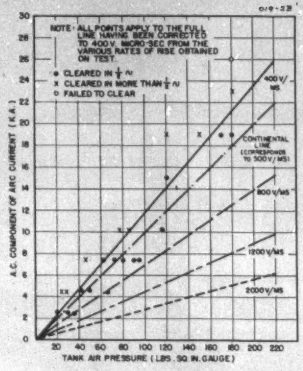
0-9-2B
NOTE - ALL POINTS APPLY TO THE FULL LINE HAVING BEEN CORRECTED TO 400 V. MICRO-SEC FROM THE VARIOUS RATES OF RISE OBTAINED ON TEST.
CLEARED IN 1/4 AV
CLEARED IN MORE THAN 1/4 AV
FAILED TO CLEAR
400 V/MS
CONTINENTAL LINE (CORRESPONDS TO 500 V/MS)
800 V/MS
1200 V/MS
2000 V/MS
A.C. COMPONENT OF ARC CURRENT (K.A.)
TANK AIR PRESSURE (LBS. SQ IN. GAUGE)

Figure 2b. Variation of rupturing capacity with air pressure, radial-type nozzle

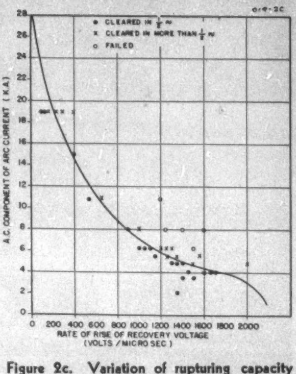
0-9-2C
CLEARED IN 1/4 AV
CLEARED IN MORE THAN 1/4 AV
FAILED
A.C. COMPONENT OF ARC CURRENT (K.A.)
RATE OF RISE OF RECOVERY VOLTAGE (VOLTS / MICRO SEC)

Figure 2c. Variation of rupturing capacity with rate of rise of recovery voltage at 120 pounds per square inch, radial-type nozzle

1,000 frames is distributed over one cycle. With this device, exposures occur at the rate of one every $16^2/_3$ microseconds, or one every 0 degree 20 minutes of arc.

Figure 4 shows some typical enlargements of arcs taken with this camera.

Although much valuable work has been done in which the voltage recovery characteristics of circuits have been assessed on the basis of the recovery rate, or the steepest tangent passing through the origin, it has nevertheless been appreciated from the earliest days of the conception that precise work along this line involved a comparison of the entire voltage recovery curve of the circuit with the curve representing recovery of insulation strength of the interrupting device. For certain other interrupting devices, notably expulsion protector tubes, curves of insulation strength recovery have been determined and published. In the present instance, therefore, an attempt was made to secure as complete a curve as possible between the recovery strength of the circuit breaker and time. In order to secure this curve the circuit breaker was subjected to varying recovery voltage rates high enough to cause the arc to restrike. A cathode-ray oscillogram of such a test shows the voltage first rising across the contacts and then collapsing at the point where a restrike occurs. The value of voltage at which collapse occurs and the associated time provides a point in the time curve of recovery of insulation strength. See appendix *C*.

The solid line of figure 5 is a plot of a recovery characteristic with a number of experimental points shown. Over a considerable range it appears that a straight line through the origin fits the observed points as closely as any other line. It therefore, appears that the conception of recovery rate, that is, a proportionate increase in strength against time, is a useful parameter for this type of circuit breaker. As the recovery voltage rises corresponding to an increasing dielectric strength in the path previously occupied by the arc, however, the point is reached where a breakdown can take place between the contacts over a new path. There is, therefore, a saturation condition. The curve bends over at some value representing the breakdown of the gap. This saturation characteristic appears as a matter of experiment in the solid-line curve of figure 5.

In figure 5, most of the experimental points correspond to a pressure of 3 pounds gauge or 18 pounds absolute. The dashed curve is calculated from the experimental solid curve for 20 pounds gauge or 35 pounds absolute. Two test points are given corresponding to this pressure. The highest points of these two curves are at 40 and 91 kv respectively, or a ratio of approximately 2.3. From the curve in figure 6, the rod-gap dielectric strengths corresponding to the two pressures and adjusted to the proper temperatures are 61 kv and 103 kv, whose ratio is 1.7. From the random nature of breakdown phenomena this is probably as close an agreement as one can expect from so few tests.

Below ten microseconds no experimental points on the solid curve appear. Some discussion will be offered as to the probable shape of the portion of the curve below ten microseconds. However, consideration will first be given to the straight portion of the curve between t_2 and t_4. This part of the curve appears to be consistent with the displacement theory of operation, that is, it is assumed that at current zero an unimpaired wedge of dielectric is driven across the arc path. This wedge increases in thickness at the rate of fluid flow and the product of that rate and the dielectric strength of the wedge gives a measure of recovery strength across the gap:

$$v/t = d/t \times v/d$$

where

v = voltage
d = distance
t = time
v/t = rate of rise of recovery voltage
v/d = dielectric strength
d/t = dielectric velocity

This equation has been evolved for the case of liquid dielectric such as oil, which is relatively incompressible and constant as to dielectric strength. With air which

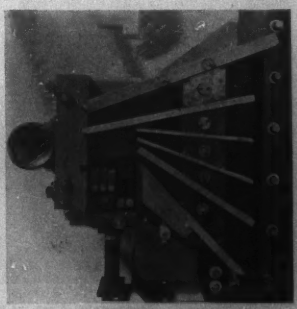

Figure 3. Cross section of interrupting unit of cross-blast air circuit breaker

Figure 4. Photographs of the arc in a cross-blast circuit breaker taken with high-speed camera at 60,000 frames per second

Frames 1 to 25 inclusive are photographs of the arc which is decreasing as it approaches current zero in frame 23. Frame 30 shows the first breakdown, at *B*, from the moving contact to a timing gap at *A*. The breakdown of this timing gap is recorded on the cathode-ray oscillogram and makes it possible to locate the current-zero photograph. In frame 32 these auxiliary arcs appear with greater intensity. Frame 22 shows the 3³/₈-inch depth of the cooling plates

obeys the gas laws and has a dielectric strength which is variable with pressure, the matter of determining the proper dielectric strength and velocity to use is somewhat more complicated than with oil. The curve of figure 6 has already been offered showing the variation of dielectric strength with pressure. The

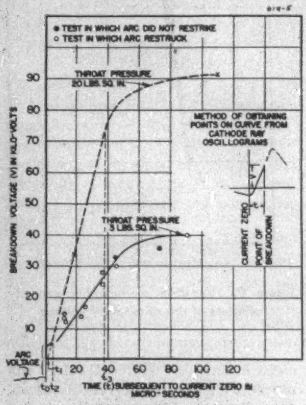
TEST IN WHICH ARC DID NOT RESTRIKE
TEST IN WHICH ARC RESTRUCK
THROAT PRESSURE 20 LBS. SQ. IN.
METHOD OF OBTAINING POINTS ON CURVE FROM CATHODE RAY OSCILLOGRAMS
THROAT PRESSURE 5 LBS. SQ. IN.
CURRENT ZERO
POINT OF BREAKDOWN
BREAKDOWN VOLTAGE (V) IN KILO-VOLTS
ARC VOLTAGE
TIME (t) SUBSEQUENT TO CURRENT ZERO IN MICRO-SECONDS

Figure 5. Variation of recovery strength of cross-blast breaker with time

amount of air discharge through an orifice is expressed by the equation:

$$M = Ap\sqrt{\frac{\gamma g}{RT}}$$

where

M = mass discharge in unit time
A = effective orifice area
P = absolute pressure in orifice
T = absolute temperature in orifice
R = universal gas constant
$\gamma = \frac{cp}{cv}$
g = acceleration of gravity

This equation holds provided the receiver pressure is less than 0.53 times pressure in the tank supplying the orifice. Under these conditions, the discharge will be at the velocity of sound. This condition is met by the 20-pound curve of figure 5. In the air at high velocity, the temperature will have fallen in accordance with the equation

$$T_3 = T_1\left(\frac{P_3}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

to −71 degrees centigrade, P_1 being 135 pounds absolute.

At this pressure and temperature the impulse dielectric strength will be 103,000 volts per inch, assuming that the gap between the ionized columns is approximately equivalent to a rod gap. At a temperature of −71 degrees the velocity of sound is 938 feet per second. The data is taken under such conditions that the contacts are separated far enough to bring in to play one barrier in the arc chute. A wedge of air will be driven in on each side of this barrier so that the rate of rise of dielectric strength should be determined by multiplying the dielectric strength just obtained by the velocity of sound and by 2. The resultant figure of 2,320 volts per microsecond is well within the limits of experimental error as compared with the slope of 2,000 volts per microsecond on the dotted curve.

In the deionization or cooling theory of arc interruption the arc space is cooled and deionized. (Doctor Suits[11] has shown that these two phenomena are substantially the same at high pressure.) This cooling causes an increase in arc voltage. Prior to current zero the arc voltage is measured and it is a reasonable assumption that immediately subsequent to current zero it would require that amount of voltage or a greater amount to sustain an arc. Practically, the required voltage should be greater for two reasons. In the first place, some cooling will have taken place during the voltage reversal no matter how quickly that has occurred. In the second place, the reversal must be accompanied by the formation of a new cathode. This cathode effect, however, is small in a high-voltage design such as that under discussion. The curve of figure 5 would, therefore, be expected to start at zero time t_0 at a height corresponding approximately to the arc drop prior to current zero. During the time that the cooling is taking place this curve will rise until when the cooling has become complete the dielectric strength will increase at the rate of interposition of new dielectric. The transition from the curve to the straight line, the slope of which represents the rate of interposition of the new dielectric, is designated as t_2. It is interesting to see what evidence can be obtained regarding the time t_0 and t_2 and what effect it has upon the performance of the circuit breaker.

In this way the recovery characteristic of this circuit breaker can be divided into two parts. One part between t_0 and t_2 in which a cooling phenomenon takes place and the other period subsequent to t_2 in which the operation is on a displacement basis. During the cooling period, displacement cannot be operative because during that period some conductivity exists, and the current flowing through that conductivity disrupts the fresh dielectric as fast as it enters the arc space. As soon as unimpaired dielectric has been interposed, that fresh dielectric will sustain the entire recovery voltage. That part of the arc path still conducting will in effect be short-circuited by that conductivity. The two phenomena, therefore, would not take place simultaneously, but are present, one prior to time t_2 and the other subsequent to it. During the time t_0 to t_1 there must be some conductivity. If that conductivity is appreciable, it should represent a resistance shunted across the contacts, and should alter the curve of the voltage transient. The voltage transient of the test station is known both through calculation and tests of oil circuit breakers. See appendix *A*.

An examination of the tests on the cross-blast air circuit breaker indicates conductivity only at currents above 6,000 amperes and at rates of rise of recovery voltage above 2,500 volts per microsecond. The largest observed conductivity was quite small, resulting in a reduction of the recovery transient peak of only 15 per cent. Qualitatively, if cooling is playing a part in the operation of the circuit breaker, one would expect to find some relationship between clearing and the arc voltage immediately prior to the last current zero, that is, it should be apparent that the circuit breaker is getting ready to clear by a rise in arc voltage prior to the current zero, at which point the clearing actually takes place.

Table I shows a number of tests made at varying currents and pressures together with the arc voltages immediately prior to the last current zero. There seems to be a purely random relation between the

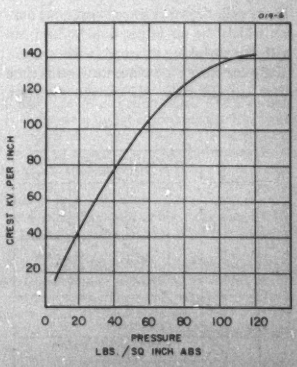

Figure 6. Variation of dielectric strength of air with pressure; impulse breakdown of two-centimeter rod gap in nitrogen at 25 degrees centigrade

arc drop just prior to clearing, so that any effect of cooling on the actual clearing appears to be a secondary phenomenon.

Further qualitative evidence on this subject was obtained by substituting other gases for air. It is known that a small amount of carbon tetrachloride vapor will greatly increase the breakdown strength of air. Accordingly, carbon tetrachloride vapor was added and it was found that the performance corresponded to that which would exist at double the dielectric strength of pure air in accordance with the displacement theory. Since it was conceivable that this increase was due in part to the increased cooling effect from added carbon tetrachloride, a proper proportion of CO_2 was added to give approximately the same increase in the cooling effect but no measurable increase in the performance was detected.

Messrs. I. Kesselring and F. Koppelman[7,8] have proposed an interesting theory on the basis of which the time required to cut the arc path can be calculated for a radial-blast breaker. They assume that the current density in the arc stream is a constant. Under these conditions and with the round arc stream used by them the diameter of the arc is proportional to the square root of the current, a relationship which they claim to have been confirmed by photographs. In the process of cutting off the arc path, the interrupting air proceeds with some velocity. As long as this velocity is greater than the rate at which the arc diameter decreases, the unimpaired air will follow closely the receding boundary of the arc. However, with the diameter changing in accordance with the square root of current, the rate of decrease of the arc diameter approaches infinity as current zero is approached. There will, therefore, be a short time during which the air is not able to keep up with the shrinking arc, and it will not actually cut off the arc space until some time after current zero. If enough data are available this interval during which the arc path is not definitely cut off by displacement is calculable.

Doctor C. G. Suits has calculated on theoretical grounds that the current density with forced convection is not absolutely constant but that it should vary in such a way that the arc diameter will vary as the 0.77 power of the current, instead of the 0.5 power as assumed by Messrs. Kesselring and Koppelman.

The high-speed photographs provide an experimental measure of the actual diameter of the arc at least as far as it is shown by its effect on the photographic negative.

Figure 7 has been taken from measurements of arcs at three different currents, peaking at 5,000, 8,000, and 18,000 amperes. From these curves the following three formulas can be deduced:

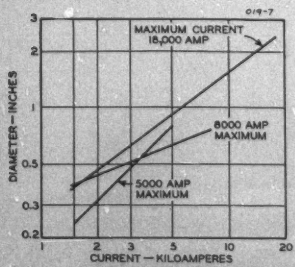

Figure 7. Variation of arc diameter with current, cross-blast circuit breaker

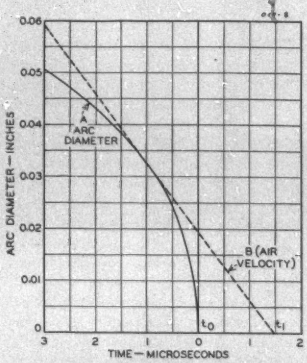

Figure 8. Variation of arc diameter with time, 8,000-ampere arc, cross-blast circuit breaker

With a maximum of 5,000 amperes

$d = 0.000288 i^{1.04}$ inches

With a maximum of 8,000 amperes

$d = 0.021 i^{0.4}$ inches

With a maximum of 18,000 amperes

$d = 0.00163 i^{0.748}$ inches

All of these curves represent measurements during the decay of the arc.

Figure 8 is such a curve of arc diameter against time, drawn to scale with a corresponding curve of air velocity shown tangent to it. If we assume that the separation of the current zero and the arrival of the air indicates the time $t_0 t_1$, then those times for the three currents observed are 0, 1.6, 0.0107 microseconds. From the pronounced variation in exponent derived from figure 7, one is left in doubt whether there is a change in constants with increase in current or whether the three sets of values are due to observational errors. More data should throw light on this point. All three values yield cutoff times so short that it is apparent that one would not expect cooling phenomena to be in evidence except under conditions of a high rate of rise. For instance the least arc voltage from table I is 2,900 volts and the longest time above is two microseconds, giving a rate of rise of 1,450 volts per microsecond.

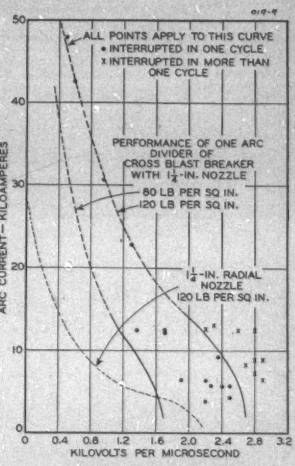
0-9-9
ALL POINTS APPLY TO THIS CURVE
• INTERRUPTED IN ONE CYCLE
x INTERRUPTED IN MORE THAN ONE CYCLE
PERFORMANCE OF ONE ARC DIVIDER OF CROSS BLAST BREAKER WITH 1½-IN. NOZZLE
80 LB PER SQ IN.
120 LB PER SQ IN.
1½-IN. RADIAL NOZZLE
120 LB PER SQ IN.
ARC CURRENT — KILOAMPERES
KILOVOLTS PER MICROSECOND

Figure 9. Variation of rupturing capacity with rate of rise of recovery voltage

This gives rise to the question of what needs to be done in the case of an application where the rate of rise of recovery voltage is extremely rapid. There are two alternatives. Either the ability of the breaker may be increased by an increase in air pressure, air volume, or the number of arc barriers introduced into the chute; or arrangements may be made to shunt the contacts with some impedance which will reduce the rate of rise. Both of these expedients can be taken. In order to secure the effect of a resistance shunt, an electrode can be located between some pair of barriers and connected through a resistance to the stationary contact. With such an arrangement the recovery voltage appearing between the contacts after the arc has been interrupted breaks down the gap to this electrode inserting the resistance in shunt with the arc path while any current flowing through the resistance is interrupted by further movement of the contact admitting air to other sections of the arc chute. In the appendix *B* will be found a simple method of calculating what

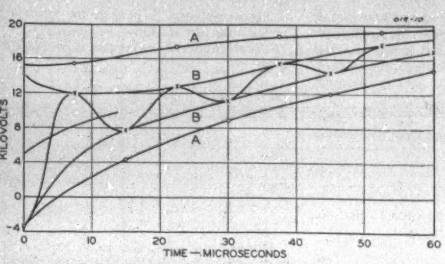

Figure 10. Envelopes of recovery-voltage oscillation, cross-blast circuit breaker

Curve *B* at reduced air pressure

the proportions of such resistors should be. From this point on, it is merely a matter of economics and design whether the recovery rate of any given circuit should be taken care of by a change in the air delivery or by the application of a shunt resistor.

The ability of the cross-blast design to handle recovery rate is much greater than that of a radial blast, particularly at heavy current.

Figure 9 is a curve of current variation with recovery rate corresponding to figure 2*c*. The curve of figure 2*c* has been superimposed and dotted for reference. In the case of the radial blast, all of the air heated by the arc and the arc products must be expelled through the same opening as the air blast. Consequently any current will reduce to some extent the air delivered. In a cross-blast design air is throttled by an orifice before entering the arc chute. As long as the back pressure is less than the critical value 0.53, the amount of air delivered will not change with current over a considerable range. The interrupting ability of the circuit breaker should, therefore, not change as much over a corresponding range and this is shown clearly in figure 9.

Some falling off in the recovery rate ability is noted, but this fall is not nearly as rapid as with the radial nozzle. At high currents gas evolved by decomposition of the chute structure begins to be added to the air discharge in such volume that it adds appreciably to the interrupting capacity of the chute. The dotted portion of the curve in figure 9 represents an extrapolation of the actual test curve beyond the point at which it was possible to secure failure to locate the curve exactly. At high currents enough gas is evolved from the chute structure to interrupt the circuit without any air supply. The extrapolation of this curve, therefore, represents ability known to be present in the interrupting structure but not necessarily the maximum capacity of it. The full-line curves of figure 9 correspond to clearing in one cycle with only one barrier in action. As the contact continues its travel two or more barriers come into action with resultant increase in interrupting ability as shown by the crosses on the figure. These points are not comparable directly with the points for one barrier since no limit in interrupting capacity was reached. It will be noted that at say 1,000 volts per microsecond the cross-blast chute interrupts over four times as much current with the same air consumption or conversely, a radial nozzle to have the same interrupting capacity would be 4.3 times as big in diameter and consume 18 times as much air.

As mentioned at the beginning of this paper, it is hoped that the foregoing will give a clear idea of the reasons why, for low-voltage designs particularly, it has been necessary to develop a new type of interrupting air-blast structure. The behavior of that structure has been analyzed and it has been shown under most conditions to operate on a displacement basis. The small area in which operation is by cooling has also been defined. For heavy currents, the ability of this design, instead of decreasing toward zero volts, actually rises until at the highest currents the circuit is interrupted even without the aid of the air blast.

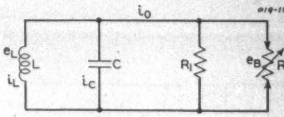

Figure 11. Test circuit

Table I. Interrupting Tests

Test Number	Arc Amperes, RMS	Arc Duration (Half Cycles)	Arc Length (Inches)	Reactor Tap Number	Kilocycles Per Second	Applied Air Pressure (Lbs Per Sq In.)	Peak Arc Voltage (Maximum Kv)	Peak Recovery Voltage (Kv)	Rate of Rise of Recovery Voltage (Volts Per Microsecond)
186	1,950	0.9	0.9	6.6/0	26	40	3.4	29	1,710
187	1,920	0.8	0.8	6.6/0	26	30	3.4	30	1,770
188	1,970	0.9	1.0	6.6/0	26	30	3.5	32	1,900
190	1,950	2.7	3.6	6.6/0	26	23	5.1	32	1,900
188	1,970	3.7	4.9	6.6/0	26	18	6.2	32	1,900
191	1,920	4.2	4.5	6.6/0	26	7	5.4	31	1,830
194	4,100	2.2	3.0	2.7/0	40	28	5.7	25	2,280
192	4,100	3.0	3.8	2.7/0	40	25	5.1	25.5	2,320
193	4,100	2.4	3.5	2.7/0	40	20	4.3	25.2	2,300
203	5,700	1.9	2.3	1.7/0	45	47	4.5	22	2,240
196	5,400	2	2.5	1.7/0	45	45	6.2	20.6	2,100
199	5,400	1.1	1.3	1.7/0	45	40	2.8	20.6	2,100
201	5,900	2.5	3.2	1.7/0	45	27	3.9	21.3	2,170
197	5,600	3.1	4.5	1.7/0	45	23	5.2	20.6	2,100
202	5,900	3.1	3.7	1.7/0	45	13	3.4	21.3	2,170
204	8,500	1.1	1.1	0.93/0	70	45	3.4	15.2	2,420
206	8,300	2.5	2.3	0.93/0	70	40	3.4	13.8	2,200
205	8,300	2.2	2.7	0.93/0	70	25	3.4	12	1,910
210	11,100	1.5	1.8	0.47/0	100	58	3.9	9.6	2,180
209	11,300	1.5	1.6	0.47/0	100	55	3.4	8.3	1,880
211	10,800	1.8	2.1	0.47/0	100	33	2.9	8.2	1,860
213	10,600	4.4	4.7	0.47/0	100	15	2.9	7.7	1,750

Appendix A. Air-Circuit-Breaker Leakage Current*

It has been pointed out that the interruption process can be divided into two periods: one during which a path of finite resistance exists between the electrodes; and a second characterized by infinite resistance but finite dielectric strength. This fact is well illustrated by a series of tests from which the actual magnitude of the leakage resistance and current are determined. It was found that at constant recovery rate, current, and voltage, air pressure could be reduced until a leakage current flowed after the current zero.

Figure 10 shows the envelopes of the recovery-voltage oscillation as taken from cathode-ray-oscillograph records of two tests taken at the same voltage and with the same circuit. Test *B* was made at considerably reduced air pressure.

The complete circuit employed in the tests consisted of a generator and an external reactance in series with the breaker. Both generator and reactance had considerable

* Prepared by Robert M. Bennett.

distributed capacitance to ground, consequently the recovery voltage was composed of two frequencies, one relatively low, and the second, due to the presence of the series reactance, of the order of 60,000 to 100,000 cycles per second.

For the purpose of analysis of the high-frequency oscillation, this circuit can be generalized as indicated in figure 11, in which L represents the inductance and C the equivalent capacitance to ground of the external reactance. R_1 represents the ordinary damping resistance of the circuit and might have been placed in series with the inductance without altering the final conclusions. R_B represents the breaker resistance. The vibration modulus of the high-frequency oscillation is:

$$p = -\frac{1}{2\frac{R_1R_B}{R_1+R_B}C} \pm \sqrt{\frac{1}{\left(2\frac{R_1R_B}{R_1+R_B}C\right)^2} - \frac{1}{LC}} \quad (1)$$

Since $2\frac{R_1R_B}{R_1+R_B}C \gg LC$ the angular frequency of the oscillation is

$$\omega = \sqrt{\frac{1}{LC}}$$

and C may be determined, the inductance being known. The envelope of the high-frequency oscillation will be of the form

$$y = \epsilon^{-\frac{R_1+R_B}{2R_1R_BC}t}$$

and this envelope plotted on semilog paper has the slope

$$D = -\frac{R_1+R_B}{2R_1R_BC} \quad (2)$$

Figure 12 shows the magnitude of the envelope of the recovery voltage during two tests, test B being at reduced air pressure.

These curves are direct evidence of the occurrence of displacement during the operation of the breaker. Curve A made at high air pressure shows that at all times after the current zero, the damping of the circuit was due to a constant value of resistance, hence the breaker resistance must have been infinite.

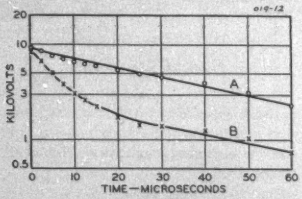

Figure 12. Magnitude of recovery voltage envelopes

Curve B at reduced air pressure

Curve B which indicates a greater rate of damping for 15 microseconds becomes parallel to curve A showing that in this case also displacement occurred although the air pressure and velocity were greatly reduced. The slope of curve A is given by $D = -\frac{1}{2R_1C}$ and the value of R_1 is found from the relation

$$R_1 = -\frac{1}{2DC} \quad (3)$$

If R_1 is known it is possible to find R_B from equation 2 above, that is

$$R_B = -\frac{R_1}{1+2R_1DC} \quad (4)$$

The above method of calculation is useful for determining the breaker resistance after the first peak of the recovery voltage. For values previous to this peak the exact value of the voltage envelope is in doubt and the breaker current can be determined as follows:

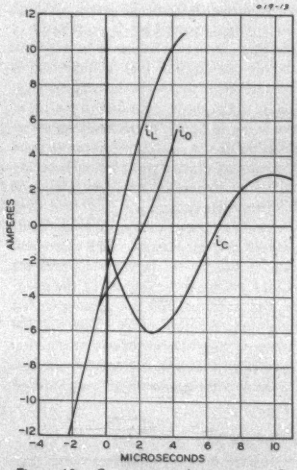

Figure 13. Construction of currents, test B

Referring to figure 11

$$e_L = -L\frac{di_L}{dt}$$

and the slope of the inductance current is given by[5]

$$\frac{di_L}{dt} = \frac{-e_L}{L}$$

The capacitor current is found from the relation $i_C = -C\frac{de}{dt}$ consequently both i_C and i_L can be drawn if any single value of inductance current can be determined. Since it is evident that i_0 must be zero when $e_B = 0$, it is possible to determine the inductance current at this instant by $i_L = i_0 - i_C = -i_C$.

These currents as plotted for the low-pressure air test are shown in figure 13.

The resistance of the breaker is then found from

$$\frac{R_1R_B}{R_1+R_B} = \frac{e_B}{i_0}$$

or

$$R_B = \frac{1}{\frac{i_0}{e} - \frac{1}{R}} \quad (5)$$

It was found that this latter method is useful only until the time of the first recovery voltage peak as the mechanics of constructing the inductance current introduce considerable error.

In figure 14 are shown the complete current, voltage, and resistance characteristics for the air breaker operating with low air pressure.

Points marked with circles are calculated from equation 5 and points marked with crosses from equation 4.

Appendix B†

Calculation of a Resistor for Controlling Voltage Recovery Rates

The ohmic value of resistance to limit the recovery rate to a given value is given by the equation:

$$R = \frac{\frac{de}{dt}\times 10^8}{\frac{di}{dt}} = \frac{\frac{de}{dt}\times 10^8}{2\sqrt{2}\pi fI} =$$

$$\frac{\frac{de}{dt}\times 10^3 \times V \times \sqrt{3}}{2\sqrt{2}\pi f \times kva} = 3.25\frac{de}{dt}\times\frac{V}{kva} \text{ (for 60 cycles)}$$

where

R = the ohmic value of the resistance

$\frac{de}{dt}$ = the specified limit of recovery rate in volts per microsecond

$\frac{di}{dt}$ = the limit of the rate of change the instantaneous value of short-circuit current just prior to interruption

f = system frequency

I = maximum available interrupting current in rms symmetrical amperes

V = application voltage in line-to-line volts

kva = interrupting duty in kilovolt-amperes, three phase

This value of resistance should be used on each pole.

The amount of active material required may be based on the allowable temperature rise for one operation on the assumption that all of the heat developed remains in the active material. If the breaker is properly designed, the maximum duty will be about one-quarter cycle at 1½ times leg voltage. The amount of active material is then given by:

$$M = \frac{Q}{h\Delta T} = \frac{950\times .75\times (kv)^2}{240h\Delta T\times R} = 2.97\frac{(kv)^2}{h\cdot\Delta T\cdot R}$$

† Prepared by W. F. Skeats.

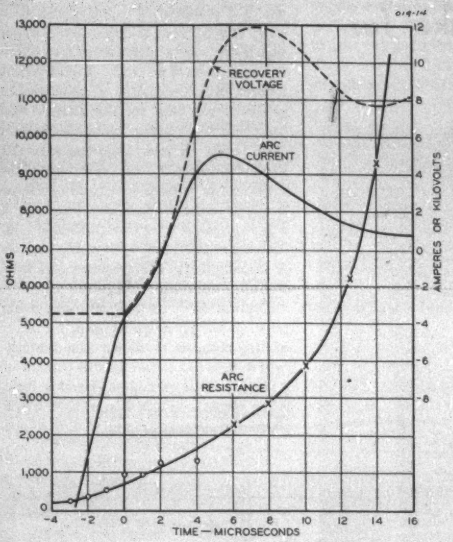

Figure 14 (left). Variation of leakage current and resistance with time

Figure 15. Breakdown in cross-blast air circuit breaker

3.7 microseconds per millimeter

Figure 16 (right). Breakdown of an arc which has been cooled to the point of interruption

A—Line voltage
B—Arc voltage
C—Current

where

M = active material required in pounds for each pole
Q = heat generated in resistance in Btu
h = specific heat of material; Btu per pound per degree Fahrenheit
ΔT = allowable temperature rise for one operation, Fahrenheit
R = resistance in ohms
kv = application voltage in line-to-line volts

Appendix C

The type of breakdown that occurs in the air-blast breaker is of particular interest because it indicates the nature of interruption to be similar to the breakdown of a dielectric. A cathode-ray-oscillograph record of such a breakdown is shown in figure 15.

The recovery voltage rises at a rate which is in accordance with circuit characteristics and then collapses to zero voltage in less than two microseconds.

This failure of the cross-blast air circuit breaker was intentionally caused by reducing air pressure and increasing the rate of rise of recovery voltage. The character of the failure is similar to that of the disruptive breakdown of a rod gap in air.

As there is nothing shown in the oscillograph record which would indicate progressive breakdown, we conclude that it was occasioned by the overstressing of the cold air of the blast which had been inserted between the arc path ends after current zero. In other words, there was an interruption by displacement but breakdown occurred due to the fact that the recovery voltage rose faster than the dielectric strength.

In contrast with this sharp breakdown the slowness of thermal breakdown is illustrated by the magnetic oscillograph record figure 16.

It will be noted that there were attempts to interrupt which were partially successful and finally the arc was extended to a point where successful interruption was obtained. The rate of rise of recovery voltage is less than ten times faster than the 60-cycle voltage wave which is less than 40 volts per microsecond and indicates that its rate of rise was limited by leakage current.

The collapse of voltage T_1 to T_2 required approximately 2,000 microseconds which indicates clearly that it was progressive in character and was caused by a gradual decrease in the resistance of the arc path.

These two cases have been chosen as they are typical of the extremes. Figure 15 is the disruption breakdown following displacement with no deionization phenomena visible. Figure 16 is the progressive breakdown from a reversal of the deionization process with no displacement in operation.

Cases may be found where displacement and deionization by cooling may both play a part in arc interruption; however, in the cross-blast air circuit breaker, displacement will account completely for interruption at low currents and be a predominating factor even for the high currents and recovery rates.

Bibliography

1. Oil Blast Circuit Breaker, D. C. Prince and W. F. Skeats. AIEE Transactions, volume 50, June 1931, pages 506–12.

2. Impulse High Speed Circuit Breaker, W. K. Rankin. *General Electric Review*, volume 34, October 1931, pages 553–8.

3. Hochleistungschalter ohne Ol, Von O. Mayr. *Elektrotechnische Zeitschrift*, volume 4, January 28, 1932, pages 75–81; volume 6, February 11, 1932, pages 121–3.

4. Theory of Oil Blast Circuit Breakers, D. C. Prince. AIEE Transactions, volume 51, March 1932, pages 166–70.

5. Arc Extinction Phenomena in High-Voltage Circuit Breakers, R. C. VanSickle and W. E. Berkey. AIEE Transactions, volume 52, September 1933, pages 850–7.

6. Investigation of Electric Arcs, Fritz Kesselring. *ETZ*, volume 55, number 4, January 24, 1934, pages 92–4; number 5, February 1, 1934, pages 116–18; number 7, February 15, 1934, pages 163–8, and 176.

7. Switching Problems in High-Tension Field, F. Kesselring and F. Koppelmann. *Archiv für Elektrotechnik*, volume 29, January 11, 1935, pages 1–33.

8. Switching Problems in High-Voltage Engineering, F. Kesselring and F. Koppelmann. *Archiv für Elektrotechnik*, volume 30, number 2 February 18, 1936, pages 71 to 108.

9. Research During 1936 on Restriking Voltage and Dielectric Strength, Kesselring and Krohne. Conference Internationale des Grands Reseaux Electriques a Haute Tension, 1937, tome 1, number 112, pages 11 to 21.

10. Electric Strength of Air at High Pressure, H. H. Skilling. AIEE Transactions, volume 58, 1939 (April section), pages 161–5.

11. Heat Transfer Methods in Arc Interruption, C. G. Suits. *General Electric Review*, volume 42, October 1939, page 432.

12. Application of Heat Transfer Data to Arc Characteristics, C. G. Suits and H. Poritsky. *Physical Review*, volume 55, number 12, June 15, 1939, pages 1184–91.

13. 120,000-Exposure-per-Second Camera, D. C. Prince and W. K. Rankin. *General Electric Review*, volume 42, September 1939, page 391.

14. Mechanical Engineers Handbook, Lionel S. Marks.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

Magnetic "De-ion" Air Breaker for 2,500–5,000 Volts

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Synopsis: The theory of quenching an arc by deionizing the normally conducting arc stream, utilizing a gas blast produced by means of an intense transverse magnetic field, is elaborated. Application of design principles dictated by this theory has made it possible to develop a new form of air circuit breaker for 2,500–5,000-volt service. These breakers are completely described, the theory of the De-ion interrupters is discussed, and test results are submitted. The problem of adequately enclosing the breakers is considered and it is shown that excellent interruption can be obtained in an enclosure of small over-all dimensions.

INTERRUPTION of 2,500- and 5,000-volt circuits capable of producing fault currents equivalent to 150,000 kva, by breakers using air as the interrupting medium, is not readily accomplished without special arc-quenching chambers. In open air impractically long arcs are necessary to clear circuits supplied at these voltages. Comparatively simple air circuit breakers have been built utilizing magnetic blowout means for lengthening the arc in an interrupting chamber of reasonable dimensions, but even with the constricted path available for the arc in such chambers, it is necessary to lengthen the arc to approximately five feet in order to achieve interruption. The energy dissipated in such an arc is necessarily high because of the long arc length and consequent high arc voltage. Interruption in such cases is not achieved primarily by establishing a process of rapid deionization in the vicinity of current zero, but depends rather upon building up the arc voltage to such an extent that restriking after an early, forced, current zero does not take place, even though intensive deionization is not provided during the time of substantially low recovery voltage following the current zero.

It is usually necessary to mount air circuit breakers for 2,500–5,000-volt applications in compact metal-clad switchgear. Consequently, efficient interruption with a minimum of arc energy, size of interrupting chamber, and formation of ionized gases is required. These features call for the development of arc-interrupting means which will open the circuit using a comparatively short arc, relatively low energy input, and effective deionization at the first current zero. In the next sections a circuit breaker is described which has these qualities and which is shown to be adequate for 150,000 kva at 2,500 or 5,000 volts when mounted in enclosures of small dimensions.

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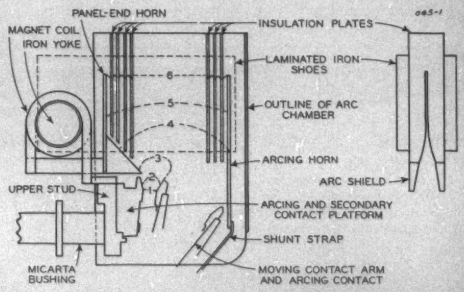


Figure 1. A diagrammatic sketch showing partial sections of the magnetic De-ion interrupter

The dotted lines 1, 2, 3, 4, 5, and 6 indicate progressive positions in arc interruption

De-ion interrupter

To interrupt an a-c circuit with minimum dissipation of energy, a switch is required which does not substantially impede the flow of current until it normally reaches zero, and which quickly takes on insulating properties thereafter. This means appears to be more advantageous than depending upon a high arc voltage and the associated high energy input to effect interruption. Synchronization of interruption with a current zero may be obtained by separating switch contacts and forming an arc which must be controlled to develop dielectric strength, following the current zero, more rapidly than voltage is impressed by the circuit.[1] This deionization action may be accomplished in a number of ways—for example, by the use of a blast of gas produced by decomposing a gas-forming material,[2] or by the use of a plurality of copper plates with short arcs between them to take advantage of the spectacular dielectric recovery at the cathode of an arc.[3] A more recent method which employs a magnetically produced gas blast for deionization was presented by Ludwig and Grissinger in their paper "A New High-Capacity Air Circuit Breaker".[4] An experimental review of the various interrupting means available indicated that this latter method was most suitable for interruption of high currents at 2,500 and 5,000 volts, because of its simplicity, effectiveness, and freedom from undesirable flame and noise.

Application of the magnetic-deionizing principle results in constructing an interrupting chamber as shown diagrammatically in figure 1. The chamber consists of a large number of non gas-forming insulating plates having V-shaped slots which are spaced apart and placed at right angles

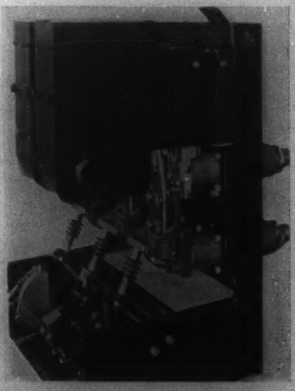


Figure 2. A right view of a 2,000-ampere magnetic De-ion breaker for 2,500–5,000-volt service

Rated interrupting capacity 150,000 kva. Right-pole arc chamber removed

to the arc path. During operation an arc is drawn between separating contacts, and is then magnetically moved toward the closed top of the slots in the insulating plates. At this position the presence of a strong magnetic field imparts to the electrons in the arc an upward component of velocity. They in turn bombard gas particles and produce an actual blast of gas perpendicular to the arc, which action requires the arc continuously to ionize fresh gas in considerable quantities. When current zero is reached this action continues in a sufficient degree effectively to deionize the plurality of short lengths of the arc near the edges of the plates. Dielectric strength is consequently established.

Figure 3. Front and side views of the new De-Ion circuit breaker for 150,000 kva interrupting capacity

A—Arcing- and secondary-contact platform
B—Moving-contact arm
C—Main-contact bridge member
D—Upper contact stud
E—Lower contact stud
F—Insulating push rod
G—Upper stud bushing
H—Lower stud bushing
I—Male adapter of magnet coil which engages the female connector of the panel-end horn of the arc chamber
J—Magnet coil
K—Panel barriers
L—Solenoid mechanism
M—Magnet shoes
N—Removable operating handle
O—Insulating magnet bushing
P—Accelerating spring
Q—Air dash pot
R—Shunt trip
S—Removable arc chamber
T—Interphase barriers

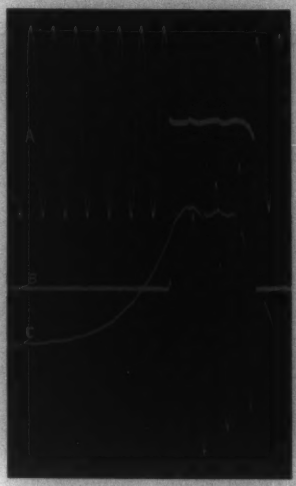
The insulating plates are made of a material which does not form gases in order to prevent unnecessary display of ionized flame in the air space above the interrupting chamber. Flame from the arc core must pass upward between the closely spaced plates for a distance of several inches before reaching free air space. During this passage contact with the cool walls of insulating material deionizes the flame so that upon reaching the free air space beyond the chamber there is no danger of external flashover of the arc chamber or to metal parts of the enclosure in which the breaker is mounted.

Figure 4 (left). Oscillogram of a 1,900-volt 39,000-ampere rms single-phase interruption

A—Arc voltage measured at breaker terminals
B—Travel record
C—Current through breaker

Figure 5 (right). Oscillogram of a "closing-opening" single-phase interruption with 1,800 volts and 38,500 amperes rms

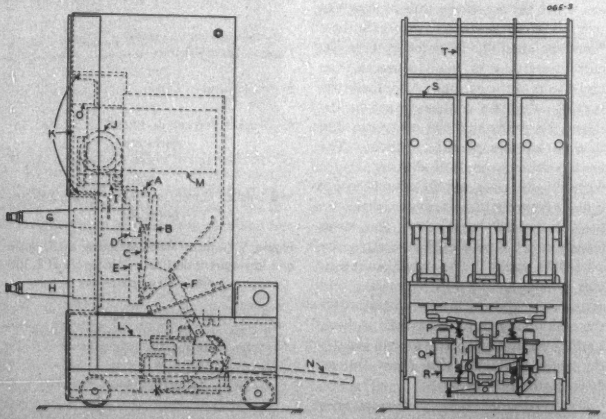
A—Voltage at breaker terminals
B—Current through breaker
C—Travel record



This principle of deionization is applicable to a wide range of voltage. The magnetic-field strength, thickness of the plates and the space between the plates, and the shape of the slot determines the volts per plate at which a given current can be interrupted. The number of plates used may be suitably chosen along with the other parameters to make the interrupter adequate for specified current and voltage ratings.

In the case of the 600-volt air breaker previously described[4] sufficient field strength to give the required volts per plate was obtained by the use of iron plates built in above the insulating plates and in the same plane with them. However, for the higher-voltage circuits iron has been added in the form of a laminated structure about the chamber, and a multiturn coil is connected to provide a very intense field. The iron structure is shown diagrammatically in figure 1.

The figure also shows an outline of one of the deionizing plates. The slot into which the arc is forced by the magnetic field is long and quite narrow at the top. When the current in the arc is high during most of the half cycle preceding interruption, the arc cannot reside in the uppermost portion of the slot because the cross-sectional area required by its core is large compared to that available in the upper slot region. The effect of this construction is to permit the arc to operate with a low voltage drop until just prior to current zero, and thus the energy dissipated in the



interruption is reduced. The arc voltage, as shown on the oscillograms in figures 4 to 9, indicates the effectiveness of the slot design in limiting the arc voltage. The design of the slot differs from that of lower-voltage breakers which are also applied for d-c interruption.

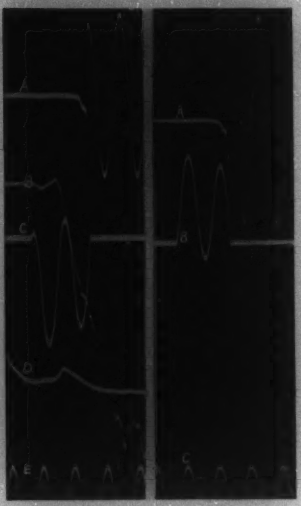


Figure 6 (left). Oscillogram of a 3,000-volt 27,500-ampere-rms single-phase interruption

A—Arc voltage measured at breaker terminals
B—Travel record
C—Current through breaker
D—Shunt-trip-coil current
E—60-cycle timing wave

Figure 7 (right). Oscillogram of a 4,000-volt 22,000-ampere-rms single-phase interruption

A—Arc voltage measured at breaker terminals
B—Current through breaker
C—60-cycle timing wave

Plates approximately one-eighth inch thick are found experimentally to be most suitable. The space between the plates may be varied from one-eighth to one-fourth inch, depending on the magnitude of the current to be interrupted and the voltage. An arc length of 9½ inches between horns at the two ends of the chamber is sufficient for interruption of 150,000 kva at either 2,300 or 5,000 volts. Rms voltages as high as 550 volts per inch or 140 volts per plate have been interrupted when the short-circuit current was approximately 22,000 amperes. An interrupting device of this type remains substantially constant in kilovolt-amperes and it is found that higher currents can be opened at lower voltages or that higher voltages can be cleared satisfactorily if the current is less.

In order to make all plates effective in the longer chutes for the higher circuit voltages, arcing horns are necessary at both ends of the chamber. These consist of copper bars placed vertically at each end of the chute. The lower terminals of the panel-end horn are sloped toward the arcing contacts of the breaker to facilitate transfer of the arc to them. The horns are slotted to release gas pressure which would tend to prevent intimate contact between the arc and the horn at the moment of transfer. The multiturn coil at one end of the chute is electrically connected between the arcing contact at that end and the horn. Therefore, the coil does not pass current except after the contacts have parted and the arc terminal has transferred to the horn, thus introducing the coil into the circuit.

Air-Breaker Construction

Breakers for 150,000 kva can be constructed in such reasonable dimensions that one can be mounted above another if desired, and therefore the draw-out type of design is particularly advantageous. The fabricated steel frame, as shown in figure 2 and figure 3, serves to support the four component subassemblies of the breaker, and has wheels attached at the bottom for withdrawal from a metal cubicle. The subassemblies are the contact structure, electric mechanism, arc chutes, and barrier system.

The contact structure of an air breaker has two functions to perform, that of carrying the load current and of drawing the arc which serves as the interrupting element. It is important to segregate these functions carefully in order to save the current-carrying or main contacts from any effects of the arcing. Also, the interrupting or arcing contacts must be designed to withstand the magnetic and thermal stresses placed on them. The main contacts are self-aligning bridge members of copper and the actual contact is made between bars of silver-nickel composition brazed to copper. The lower main contact is protected from arcing by a parallel shunt. The upper main contact is shunted by both secondary and arcing contacts which open in turn after the main contacts have parted. A horizontal overlapping barrier system isolates the main contacts from gases thrown downward by the arc.

The necessary relative motion between the two upper contacts and the main contacts is obtained by limited travel of the upper contacts on the stationary-contact side of the switch. The upper contact springs are enclosed by a platform member which has limited travel, and are thereby well protected from burning. An inverted U shunt is also enclosed within this platform member and is designed so that the magnetic force set up by the short-circuit current presses the secondary contacts tightly together in addition

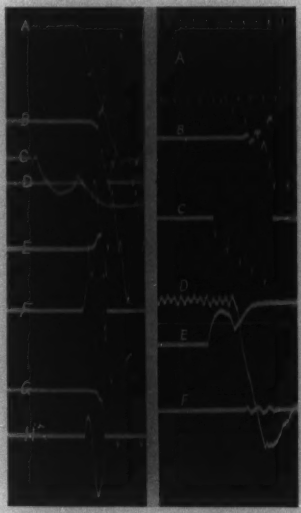


Figure 8 (left). An oscillogram of a three-phase interruption at 2,300 volts, 124,000 kva

A—Travel record
B—Arc voltage of phase 1 to neutral, 1,640 volts
C—Shunt-trip-coil current
D—Breaker current of phase 1, 27,500 amperes rms
E—Arc voltage of phase 2 to neutral, 1,640 volts
F—Breaker current of phase 2, 39,000 amperes rms
G—Arc voltage of phase 3 to neutral, 1,640 volts
H—Breaker current of phase 3, 26,000 amperes rms

Figure 9 (right). Representative oscillogram of a low-current shot on a single pole at 2,300 volts, 630 amperes rms

A—60-cycle timing wave
B—Arc voltage across breaker terminals
C—Current through breaker
D—Travel record
E—Shunt-trip-coil current
F—Indicator wave

to the springs. Parallel-path protection is thus provided for the main contacts to prevent them from opening any portion of the interrupted current. Tungsten-alloy contacts are provided for the secondaries and arcing tips.

Insulation of the contact structure and mechanical support is obtained by Micarta bushings through which the electrical connection is carried to the rear of the breaker.

The electric operating mechanism together with trip-free levers comprises a unit which is mounted horizontally in the base of the breaker. The mechanism actuates a cross bar which is mechanically connected to each moving contact arm by an insulating operating rod. The principal advantage of the mechanical construction is high speed, which results in only a half cycle of arcing at most currents.

The arc chamber previously described is withdrawn from the breaker by pulling forward and using the laminated iron field structure as a support.

The function of the barrier system is to isolate electrically the live phases from each other and from the metal enclosures, particularly during the interrupting period when free ionized flame tends to expedite flashover. Obviously, the requirements of the barrier system are lessened if the interrupting chamber is made efficient so that only a small quantity of flame is allowed to escape. An enclosed space is provided by the barrier system above each arc chamber for the discharge of hot gases, which would otherwise build up pressure above the arc in the chute and hinder its interrupting ability. In this space the gases mix with cool air, and residual flame is suppressed. Muffling action is also secured by the barriered space. The barrier structure is built as a unit of insulating material and is supported from the breaker frame at the top.

Figure 10. Arc chamber which was used during 27 interruptions at maximum short-circuit currents and also for 76 interruptions at currents of 14,000 amperes and below. The insulating plates are in satisfactory condition for further service

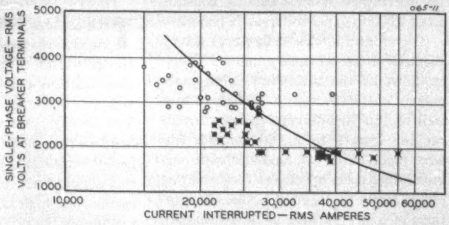
Test Results

Interrupting tests have been made on the breaker through a voltage range of 1,900 to 4,000 volts single phase, using the maximum plant capacity of the Westinghouse high-power laboratory. Figure 4 is an oscillogram showing the interruption of 39,000 amperes rms at 1,900 volts across one pole of the breaker. The equivalent three-phase kva is 150,000. The voltage element connected across the breaker terminals shows that the arc drop remains comparatively low until nearly the end of the single half cycle of arcing.

Figure 5 shows a closing-opening operation at the same voltage and with the same plant setting. The crest value of the current following closure was 89,000 amperes, and the rms current interrupted was 38,500 amperes.

Figure 6 shows the interruption of 27,500 amperes rms at 3,000 volts single phase. In figure 7, the interruption of 22,000 amperes rms at 4,000 volts single phase is illustrated. Both oscillograms show less than a half cycle of arcing.

Figure 11. Magnetic De-ion circuit breaker single-pole interruption tests



Crosses indicate tests made on a single arc chamber whose insulating plates were spaced one-fourth inch apart

Circles indicate tests made on a similar arc chamber whose insulating plates were spaced one-eighth inch apart

A three-phase interruption record is illustrated in figure 8. The line-to-line potential in this case was 2,300 volts. The total kilovolt-amperes interrupted was 124,000, and the rms current opened by the center phase was 39,000 amperes rms. This test was made with the breaker completely enclosed in a metal cubicle which was at ground potential. Demonstration such as flame was entirely absent, and noise was at an acceptably low level.

Interrupting tests have been made throughout the current range with 2,300 volts across a single pole. The time of interruption increased to 20 cycles at 22 amperes, and then decreased to one-half cycle at 9 amperes. All interrupting tests were made with only reactance in the circuit, and consequently at low power factor. The typical oscillogram of figure 9 shows an interruption of 630 amperes rms at 2,300 volts single phase.

The arc chamber is not damaged by high-current short circuits. Figure 10 shows a photograph looking up into an arc chamber which had been used during 27 interruptions at the maximum short-circuit current of the laboratory, and in addition 76 interruptions of currents of 14,000 amperes and below at 2,300 volts single phase. The oscillograms of figures 4, 5, and 9 and phase three of figure 8 were made using this De-ion chamber.

In figure 11 points are plotted to semi-log scale of currents interrupted at various single-phase voltages. Sixty-one test points are shown, based on currents inter-

rupted up to 55,000 amperes rms at 1,900 volts, and voltages as high as 4,000 volts, single phase. A curve corresponding to 150,000 kva is also drawn, and the number of successful operations above the curve and throughout the voltage range indicate a good margin of safety in the breaker over this rating. This figure also indicates that the kilovolt-amperes which can be interrupted is substantially constant from 1,900 to 4,000 volts, single phase.

The crossed circles of figure 11 are indicative of the previously noted 27 interruptions at the maximum short-circuit current of the laboratory. These tests as well as the 76 interruptions of currents ranging from 9 to 14,000 amperes rms were made on an arc chamber with one-fourth-inch spacing between the insulating plates, figure 10. The 34 circled interruptions of figure 11 were made on this arc chamber using similar insulating plates spaced one-eighth inch apart.

Conclusions

The high efficacy of the new De-ion circuit breaker to function at and above 150,000 kva with 2,500 to 5,000 volts demonstrates the practicability of the interrupter utilizing a gas blast which is produced by means of an intense transverse magnetic field. This interrupter is particularly desirable because the noise and demonstration usually found in air-circuit-breaker practice is greatly reduced. The ionized gases and other by-products of arc interruption are sufficiently controlled by the interrupter that unusual barrier arrangements are not needed. The new De-ion air circuit breaker is a particularly compact and sturdy device for use in modern clad switchgear, or for separate mounting.

References

1. Extinction of an A-C Arc, J. Slepian. AIEE Transactions, volume 47, October 1928, page 1398.
Theory of the De-Ion Circuit Breaker, J. Slepian. AIEE Transactions, volume 48, 1929, page 533.

2. The Expulsion Fuse, J. Slepian and C. L. Denault. AIEE Transactions, volume 51, March 1932, page 157.

3. Structural Development of the De-Ion Circuit Breaker, R. C. Dickinson and B. P. Baker. AIEE Journal, February 1929.

4. A New High-Capacity Air Breaker, L. R. Ludwig and G. G. Grissinger. AIEE Transactions, volume 58, 1939, page 414.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

Design and Construction of High-Capacity Air-Blast Circuit Breakers

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THE air-blast principle of circuit interruption is a recent introduction to the United States, although interrupting devices utilizing compressed air have been available in Europe for a number of years. The service performance of European breakers has been satisfactory, but inherent limitations prevented adoption in this country where large values of fault current and high rates of rise of recovery voltage are the rule rather than the exception. Exhaustive tests on forms of available air breakers heretofore available have shown that approximately 40,000 amperes represents the maximum current that can be safely interrupted at generator voltage, and then only under conditions of moderate rate of rise of recovery voltage. This fact alone made it essential, if air breakers were to be utilized, to develop an entirely different type, since applications in this country have commonly required oil breakers with interrupting ratings up to 60,000 amperes at 15 kv. Even this value of current does not represent the maximum requirement, since an increasingly strong demand exists for ratings at least up to 100,000 amperes at 15 kv or 2,500,000 kva.

It was believed that the principle of arc interruption by means of compressed air was sound, particularly for the higher interrupting ratings, so a development program was undertaken to overcome the previous limitations. Breakers with interrupting ratings as high as 1,500,000 kva (60,000 amperes at 15 kv) have already been built and tested, and design tests have been made which assure the availability of breakers of higher ratings when required by the industry. Two breakers rated 500,000 kva have been in service since early in November 1939, on the Consolidated Edison system. A number of 250,000-kva breakers of this same general type have been supplied for use on systems of the American Gas and Electric Company.

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Theory of Operation

The principle of interruption of the air-blast breaker is similar in many respects to the principles that have been thoroughly substantiated by both service experience and factory test with the oil-blast breaker. Fundamentally the theoretical basis of operation of the breaker is the displacement of the arc stream and the replacement of the arc products with insulation at a rate which will prevent break down of the dielectric by the recovery voltage. As applied to the air-blast breaker a stream of air under pressure displaces the arc stream and at the zero point of the current wave, purges the interrupting chamber of the hot gases. The flow of air across the separating contacts then provides the necessary dielectric strength at the required rate to prevent breakdown by the recovery voltage. A more complete exposition of this theory as applied to the air-blast breaker is contained in a companion paper by Messrs. Prince, Henley, and Rankin (*Transactions pages 510–17*).

Design Features

The actual design features of the breaker may be broken down into four major components in order to facilitate description:

1. Arc chute and movable contact
2. Air-blast valve
3. Operating mechanism
4. Control valve

The arc chute is a box structure of simple, compact design combined with great mechanical strength. Within this structure are the interrupting chamber, stationary contacts, cooling plates, arc barriers, and exhaust vent. Figure 1 illustrates the arrangement of the various parts of a typical chute designed for a 15-kv breaker with an interrupting rating of 500,000 kva. This chute is mounted in the breaker cell on porcelain insulators, and arranged to be easily removable for inspection.

The section at the right containing the fixed contacts, is the chamber in which the actual interruption of the arc occurs. The sides consist of blocks of insulation material with a contour designed to force the blast of air directly across the arc stream. A false top barrier containing an opening with relatively small clearances, through which the movable contact passes, forms the top while the back plate of the arc chute is also the back of the interrupting chamber and contains the entrance orifice for the air blast. The fixed-contact assembly is at the bottom of the chute, centrally located between the two insulating blocks.

Arc barriers placed at the exit of the interrupting chamber divide this portion of the interior of the chute into four passages each equipped with cooling plates. A fifth passage which also contains a cooler exists between the false and actual top barriers. All of these passages exhaust into a vertical vent where additional cooling members are installed.

The orifice in the back plate of the arc chute is located so that the normal flow of air is directly across the fixed contacts and in the plane of the longitudinal axis of the tips of the fingers. This flow of air forces the arc between the streamlined side members of the interrupting chamber and into the exit passages at the front of the chamber. In order to obtain short arc duration and minimum deterioration of parts, approximately 15 cubic feet of free air at 150 pounds initial pressure are required for a closing-opening operation on a triple-pole 15-kv 500,000-kva breaker while a 1,500,000-kva breaker requires approximately 25 cubic feet for such an operation.

The arc barriers are for the purpose of cutting the arc into sections and securing a maximum rate of increase in dielectric strength of the arc path. These barriers are of different thickness in order to equalize deterioration under the various interrupting conditions within the rating of the arc chute. The area of the passage enclosed by the barrier is proportional to the current to be interrupted while the number of passages is determined by the maximum rate of rise of recovery voltage. For 15-kv applications, tests have shown that normal interruptions up to full rating usually utilize only the first passage. The additional passages provide adequate factors of safety where high rates of rise of recovery voltage may be encountered and for that reason three barriers are used in the 15-kv arc chutes to form four exhaust passages.

The coolers are composed of stacks of thin copper plates located in the plane of the exhaust. These perform the function of cooling the exhaust gas to a point where it will not cause restrike on the outgoing side of the chute. The size and number of these stacks are determined by the current-interrupting rating.

The passage above the false top barrier allows the moving contact to be withdrawn without the external discharge of hot gases. It provides a chamber in which the time for the contact to pass through is sufficiently long to permit the air flow to completely purge the arc chute following circuit interruption, before uncovering the opening in the top barrier. The action within the section formed by the false and top barriers provides what is in effect a turbulent seal to prevent discharge around the moving contact without the necessity of a complex mechanical seal. The moving contact then finishes its stroke at which time it is completely withdrawn from the arc chute, thus providing the positive insulation of a clear air-break distance between open contacts. This also facilitates contact inspection, since the blade and its arcing tip are readily visible from the front of the cell when the breaker is open.

The exhaust gases are collected in a vent pipe of insulation material, where they are permitted to further cool and expand. Complete cooling and elimination of objectionable noise are assured by the final set of cooling plates located at the upper end of the vent pipe, where discharge takes place in the open air.

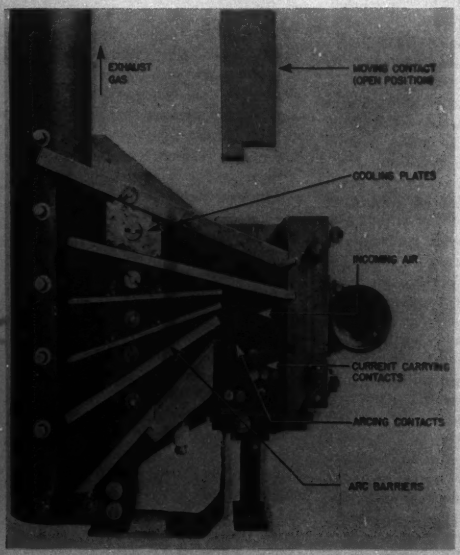

Figure 1. Cross section of arc chute of 500,000-kva breaker

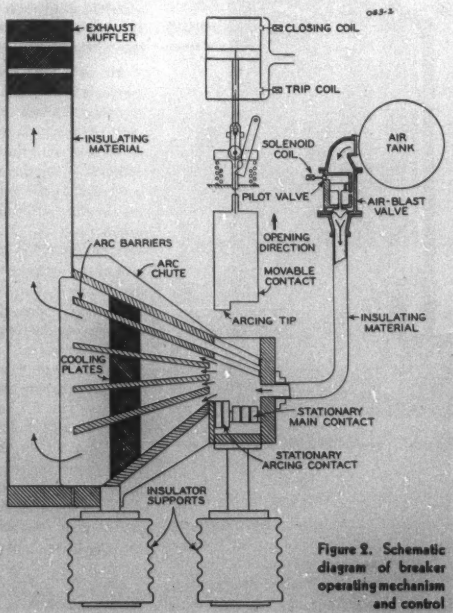

Figure 2. Schematic diagram of breaker operating mechanism and control

The stationary contacts consist of a suitable number of primary fingers to carry the normal rated current without excessive heating and secondary fingers consistent with the maximum current to be interrupted. The primary fingers are of the short-wipe line-contact silver-surfaced type that have been employed on various types of oil breakers for a number of years. These fingers are spring loaded with one end in contact with the stationary block and the other in contact with the movable blade, assuring a high-pressure silver-to-silver connection with the complete elimination of flexible shunts.

The secondary contacts consist of heavy copper fingers, surfaced on the burning area with a silver-tungsten alloy to minimize deterioration and prolong the life of the entire stationary contact assembly. These fingers are provided with a copper shunt to eliminate burning caused by vibration at the instant the movable blade engages the stationary contact, and facilitates current transfer on the opening operation. The secondary fingers are arranged to engage first and break last and, thereby, prevent burning on the primary

Figure 3. Typical 500,000-kva breaker complete in steel cell

contacts. An arcing plate has been incorporated in the design to further increase the number of interruptions that can be obtained without seriously deteriorating the stationary contacts. The burning surfaces of this plate are surfaced with a silver-tungsten alloy and are so placed that the arc is immediately transferred to it by the blast of air so the majority of the arcing occurs at this point instead of on the secondary fingers. All of these contacts and the stationary arcing plate are mounted as a unit assembly, which is easily removable from the chute for inspection or renewal.

The movable contact is a flat blade of copper, completely silver-surfaced, and equipped with a silver-tungsten alloy arcing tip. Silver-surfaced fingers, similar to the primary fingers, are mounted on the movable contact guide to provide a connection between the blade and entrance bushing. This method of making connections between movable and stationary current-carrying members is simple and compact, eliminating flexible leads or pigtails. Adequate tests have proved it to be satisfactory under all possible operating conditions.

In order to arrive at a satisfactory design of arc chute, numerous tests were made on various configurations and in many cases the action that takes place within the chute during interruption, was photographed.* The following description of the operation is, therefore, based on analysis of these high-speed photographs, as well as magnetic and cathode-ray oscillograms, which studied jointly, were of considerable aid in understanding the underlying theory and actual operation of the air-blast breaker.

Air, at a tank pressure of 150 pounds gauge, is introduced into the interrupting chamber through an orifice in the back plate of the arc chute and is so timed as to be present just prior to the parting of the contacts. The direction of flow of air is controlled by the contour of the interrupting chamber which also confines the arc to a definite path. Under this controlling condition, the flow of air forces the lower root of the arc from the tips of the secondary fingers to the surface of the arcing plate and is effectively prevented from restriking on the finger contacts by the positive flow of air. Arcing occurs on the secondary fingers for only a small fraction of the total arcing time and it is, therefore, possible to form a very accurate estimate of the condition of the stationary contacts from an inspection of the movable blade, which is fully exposed when the breaker is in the open position.

As the contacts move further apart the arc is forced into the first passage of the chute and lengthens rapidly. At the first current zero the stream of air removes the heated gases from between the contacts, placing a stream of clean air under pressure across the normal arc path. If the separation of contacts is sufficient for the dielectric strength of the air to withstand the recovery voltage, the arc has been successfully cleared. Inasmuch as the air in the interrupting chamber is under pressure, its dielectric strength is considerably greater than under normal atmospheric conditions and is sufficient to prevent restriking of the arc with only a short separation of the contacts.

If the contact separation at the first current zero has not been great enough to withstand the recovery voltage, the arc restrikes and interruption will occur at the next current zero. As the contact separation increases, additional barriers are brought into action forcing the arc to follow a path of rapidly increasing length. The speed of separation of the contacts is approximately three inches per cycle during this part of the stroke and by the second current zero from parting of the contacts, the separation is adequate to prevent the recovery voltage from causing the arc to restrike.

The movable contact is finally completely withdrawn from the chute, and during its passage through the last section, the gases are swept from the arc chute, and the air blast is shut off before uncovering the opening in the top barrier.

During the closing operation a blast of air is started across the contacts just prior to the time they meet. This very effectively prevents the arc from striking on the current-carrying parts and sweeps clear of the chute any gases which may be formed when the arcing contacts meet.

Blast Valve

For the arc chute to function properly, it is essential that a reliable valve be used to control the admission of the air blast. A high-speed differential-type solenoid-pilot operated valve has been designed for this purpose. The valve consists essentially of a bronze body with integrally cored air passages, a piston-operated main valve, and a solenoid-operated pilot valve. Poppet-type valves in conjunction with moderately soft seats have been utilized for their simplicity, speed of operation, and low leakage factor. It is of primary importance that the pressure drop of the valve be kept as low as possible and every effort has been made to provide a straight-line flow with a minimum of obstructions. Under intermittent flow conditions at a rate of 7,800 cubic feet of free air per minute, the pressure drop through this valve

* "The Cross-Air-Blast Circuit Breaker", D. C. Prince, W. K. Rankin, and J. A. Henley, *Transactions pages 510–17.*

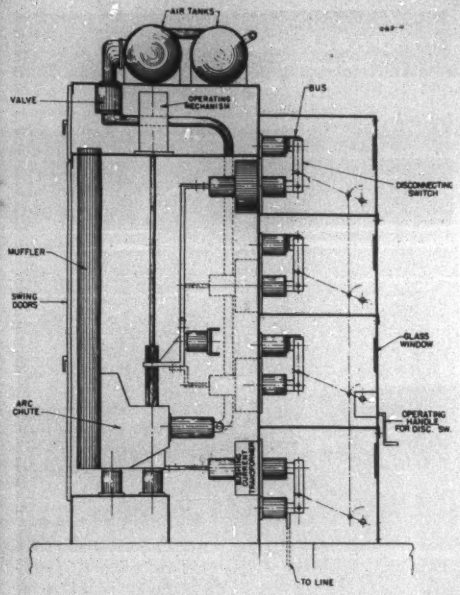

Figure 4. Application of air-blast breaker to metal-enclosed cubicle arrangement, complete with bus, disconnecting switches, and current transformers

is only about 10 pounds with an initial tank pressure of 150 pounds gauge. High speed of operation has also been obtained as the over-all operating time, from energizing the pilot valve control to complete opening of the main valve, is less than 2 cycles on a 60-cycle basis.

The blast valve is opened by energizing a solenoid, unbalancing a spring-loaded pilot valve. This allows the air to escape from above the piston at a greater rate than can be supplied by a small bleed hole from the high-pressure system. The unbalance in pressure on the two sides of the piston causes the piston to move, lifting the main valve from its seat. At the end of the piston stroke a small valve in the piston face is automatically opened, permitting a rapid flow of air to the area above the piston, but not sufficient to influence the operation as long as the pilot valve is open. This arrangement assures rapid closing of the pilot valve. With the valve in the closed position, the air under pressure holds it closed and prevents leakage.

Operating Mechanism

Mechanical operation of the contacts of this breaker is by means of a pneumatic mechanism, utilizing air pressure for both the closing and opening strokes.

Essentially the operating mechanism consists of two units, a double-ended driving cylinder and a straight-line linkage mechanism. Figure 2 shows a schematic diagram of the mechanism and control-valve equipment. The piston is directly connected to the straight-line linkage mechanism through a pair of slotted links which permit a short stroke of the piston before motion is transmitted to the contacts. To close, air pressure is applied to one end of the cylinder until the breaker is completely closed and latched in this position by a prop. On completion of the stroke, a mechanically operated switch opens to de-energize the closing control-valve solenoid.

The blast of air on closing is controlled by an interlock switch which both energizes and de-energizes the solenoid on the blast valve pilot at a predetermined point in the stroke.

The opening operation is practically the reverse of the closing operation. Air is applied to the opening side of the piston, and the first part of the motion provided by the slotted link arrangement is utilized to remove the latch. The accelerating springs rapidly bring the movable contact up to speed which is maintained by the air pressure until the blade passes the false barrier in the arc chute. At this point motion is decelerated by the action of a special dashpot, before allowing the operation to be completed. As in the case of the closing operation, air completes the opening stroke and is then cut off by a mechanically operated switch.

At the point where the blade is passing through the last section in the arc chute, an interlock switch opens to de-energize the blast of air. The mechanically operated switches used in the control of the mechanism and blast valve are directly

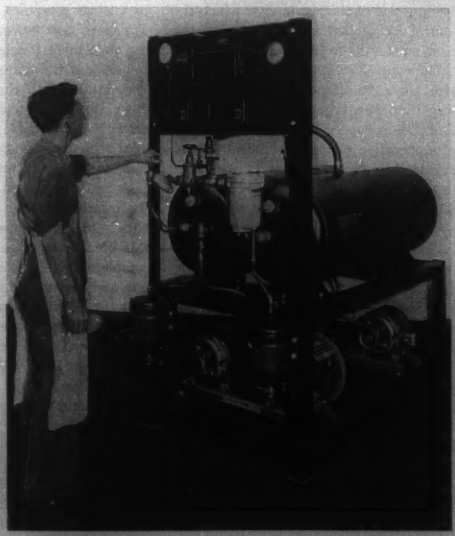

Figure 5. Typical compressor equipment for battery of 12 500,000-kva breakers

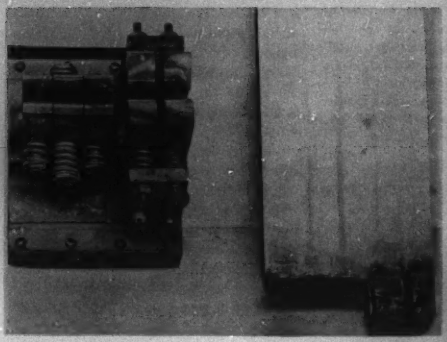

Figure 6. Condition of stationary and movable contacts following test

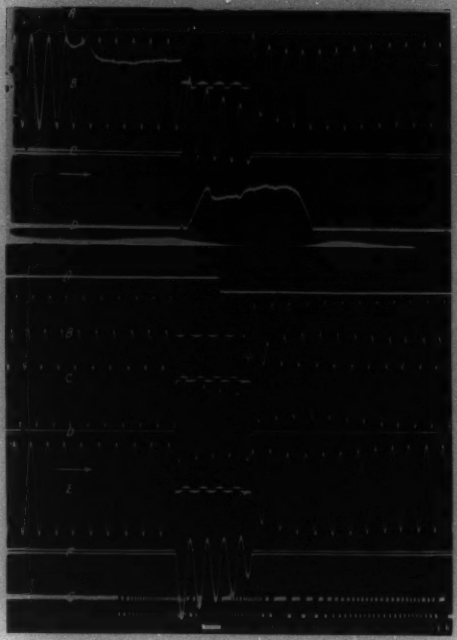

Figure 7 (right). Oscillogram of three-phase closing-opening test, interrupting 680,000 kva at 14,500 volts

connected to the mechanism. They are easily and accurately adjusted by movable cam surfaces and are of a simple and rugged construction.

Control Valves

On closing the operation is controlled by energizing the closing control-valve solenoid to admit air to the closing end of the cylinder after which the remainder of the operation is performed automatically by the sealing-in circuits and interlock switches. The opening stroke is initiated by energizing the blast-valve pilot since it is of primary importance to insure air being present at the contacts at the time of their parting. The blast-valve control is energized and motion of this valve actuates the valve which admits air to the opening side of the piston after which the control is handled automatically in the same manner as on the closing stroke.

The control valves used in conjunction with the mechanism are of the spring-biased poppet type with soft seats to minimize leakage. In order to prevent a false operation of the mechanism in case leakage does occur, the valves are so arranged that the passage to the cylinder is open to the atmosphere when the valves are in the closed position.

The closing and opening valves are interlocked in such a manner that the opening valve takes precedence over the closing valve under all conditions and provides the necessary trip-free operation of the mechanism. The operating mechanism is, therefore, fully trip free since an opening operation may be initiated at any time during the closing stroke.

General Arrangement

Figure 3 shows a typical 500,000-kva breaker mounted in a steel cell, with both terminal connections located at the bottom, and with the mechanism and air storage tank mounted at the top. A bottom-and-back arrangement can also be made in this same type of structure. Conclusive tests have shown that the interrupting element of this breaker is insensitive to position; the contacts may be mounted horizontally with the blast either up or down, or the moving contact may be drawn downward. Therefore, where local structural conditions require, an arrangement may be made with the storage tank and mechanism at the bottom, and the terminals at the top or the top and back. Figure 4 shows the application of this breaker to a metal-enclosed cubicle complete with disconnecting switches, bus, and current transformers. This construction provides a ready means of interlocking the gang-operated disconnecting switches with the cell doors, to permit entrance to the breaker cells only when the parts are safely disconnected from both bus and line.

Air Supply

In the case of these high capacity breakers, each breaker will have its own individual air storage tank, containing a sufficient supply for two closing-opening operations at full interrupting rating. A central compressor and storage system may be located at any convenient remote point, and connected by a manifold and nonreturn valves to the breaker unit tanks. These nonreturn valves assure the retention of sufficient air at each breaker for two operations in the event of failure of the central system.

The size and nature of the central compressor and storage plant will be determined by the number of breakers to be supplied, and the probable frequency of operation. The 500,000-kva breaker uses only about 15 cubic feet of free air per round trip operation. In one typical installation of these breakers, compressors rated 5 cubic feet per minute are used. These are operated by two-horsepower motors so with both the main and auxiliary compressors connected to operate, their running time will be about $1^1/_2$ minutes per breaker operation. Figure 5 shows this compressor and storage equipment, adequate for 12 500,000-kva breakers, for average central-station service. Two 5-cubic-feet-per-minute compressors are used, either one or both of which may be selected to hold the primary tank pres-

sure automatically within selected limits.

For indoor service, the moisture content of the air is of concern only in so far as it might cause sticking of the valves, since it has no effect on the interrupting performance of this type of breaker. To secure the required degree of dryness in the air, therefore, this system compresses to 250 pounds pressure in the primary tank where the air is cooled, dropping most of the moisture content. An automatic reducing valve feeds the secondary tank at 150 pounds pressure with dry air, which has been found to have a dew point below zero degrees Fahrenheit, which is entirely safe for indoor service. In addition to the automatic pressure controls for the compressor motors, the usual water pumps, oil traps, and safety valves complete this part of the equipment.

Each individual breaker storage tank is equipped with a pressure switch, which at any predetermined low pressure can be arranged to perform one of three functions:

1. Sound an alarm
2. Trip the circuit breaker
3. Lock the breaker against tripping

The type of service on which the breaker is used, will generally determine which of the three alternatives should be selected. This switch is equipped with a manually operated by-pass, so that the operator may elect to trip the breaker to clear normal load current, which requires only very low air pressure, when the air in the tank might not be adequate for full interrupting rating performance.

Tests

A very comprehensive series of interrupting tests was brought to a climax in August 1939 by a demonstration of the 500,000-kva breaker to a large group of interested engineers, at the high-capacity testing station at Schenectady. The breaker was subjected to both opening and closing-opening tests over a range from 10 per cent to 150 per cent of interrupting rating. Table I summarizes the results of these tests, indicating that the longest arcing time was 0.5 cycle and the longest breaker operating time 6.0 cycles.

Additional tests were made on this same breaker following this series, making a total of some 20 operations, 13 of which were at or above full rating. Following this complete series, the contacts shown in figure 6 were still in condition to permit making many more tests without attention.

Figure 7 is a typical oscillogram taken during this series of tests, and shows a three-phase closing-opening operation at 27,000 amperes, 14,500 volts, or slightly above full rating of the circuit breaker.

One of the unique features of this type of interrupting device is its high current-closing ability. The blast of air during the closing operation effectively delays the striking of the arc until the contacts have practically touched, and then promptly clears away the gases which are generated. Table II, test 1, shows the results of a typical three-phase closing-opening test at 4,200 volts in which the breaker successfully closed against a peak current of 197,000 amperes and then tripped and cleared. Test 2 was an opening test at 4,200 volts across a single-pole unit, in which the breaker cleared a current of 78,000 rms amperes, initial in arc.

In the course of making tests for design information, at reduced pressure levels, or with experimental timing of blast-valve opening with respect to contact separation, occasional operations were encountered when the breaker did not clear, and in due course of time the fault was removed by the station back-up breaker. In such cases arcing continued within the interrupting chamber, melting contact parts, and destroying some of the material of the arc chute. However, no damage resulted to the cell or enclosing structure, either by disruptive forces or by arcing. In all cases the breaker was again ready for service inside of two hours after merely replacing contact parts and barriers.

Table II

Test Number	Duty	Current, Amperes: Maximum Loop Peak Value	Current, Amperes: Maximum Loop RMS Value	Initial in Arc, RMS	Kva, Three Phase	Cycles From Trip Impulse to Interruption	Arc Length (Cycles)
1	CO	166,000	98,000	44,000	350,000	4.9	0.80
		197,000	112,000	48,000			1.05
		105,000	68,000	48,000			0.45
2	O	163,000	97,000	78,000		3.8	0.70

Conclusions

Oilless circuit breakers for indoor service are now available for the first time in interrupting ratings completely covering the range of oil breaker ratings. A number of high-capacity units has been placed in service, and a 1,500,000-kva 15-kv triple-pole unit has been built and completely tested. A review of the design and tests on the air-blast breaker brings out the following:

1. Complete elimination of fire hazard
2. Positive operation, with arcing time closely approaching the irreducible minimum
3. Contacts and arcing compartment built for long life, and minimum deterioration
4. Arcing contact exposed for ease of inspection
5. Flexibility of mounting arrangement, permitting either bottom, back, or top connections
6. Space requirements equal to, or less than correspondingly rated oil breakers, which is of importance in modernization of old stations or extensions of existing switchhouses
7. Simplicity and compactness of application to steel cubicle construction, which is easy to install, safely interlocked, and having all design features co-ordinated
8. High inherent current-closing ability

Table I. Three-Phase Tests at 14,500 Volts

Test Number	Duty	Current, Amperes Maximum Phase: Maximum Loop Peak Value	Current, Amperes Maximum Phase: Maximum Loop RMS Value	Initial in Arc, RMS	Kva, Three Phase	Cycles From Trip Impulse to Interruption	Arc Length (Cycles)
1	O	4,400	2,800	2,100	53,000	5.9	0.05
2	O	12,000	7,000	5,400	135,000	5.4	0.1
3	O	32,000	19,500	13,500	340,000	5.0	0.05
4	O	48,000	29,000	19,000	480,000	5.8	0.2
5	O	55,000	32,000	25,000	630,000	5.9	0.3
6	CO	48,000	29,000	20,000	500,000	5.9	0.3
7	CO	80,000	49,000	29,000	730,000	6.0	0.5

Discussion

Discussion will be found in the 1940 annual TRANSACTIONS volume and in the 1940 "Transactions Supplement" to ELECTRICAL ENGINEERING.

A New 15-Kv Pneumatic Circuit Interrupter

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Synopsis: The demand for oilless circuit breakers of large interrupting capacity to meet the requirements of American practice directs attention toward an improved compressed-air circuit breaker which materially extends the present limitations as exemplified by continental designs.

A brief historical review of the trend toward oilless-circuit-breaker development is given. The comparison is made of the available methods of circuit interruption in air. The particular applicability of compressed air is stressed and a new circuit interrupter is described which can reach an interrupting capacity of 1,500,000 kva at 15,000 volts. Among the outstanding features of this interrupter are extremely high operating speed and rapid interruption with minimum energy dissipation. Test results are given indicating the adequacy of this type of design.

THE circuit-breaker art, almost from the time of its inception, has depended upon the use of oil as an interrupting medium in the larger and higher-voltage units. The choice of oil was based upon its excellent insulating properties and its remarkable arc-quenching ability. Oil, and its vapor, can be ignited, however, and thus can constitute a serious fire hazard, as the result of abnormal circuit-breaker operation. This factor has long been recognized, but practical operation of electrical systems has demonstrated that oil fires directly chargeable to circuit-breaker failures have been negligible. Recently, however, growing demand on the part of operators and development of the principles of oilless circuit interruption in Europe have combined to strengthen the interest in oilless circuit breakers in this country.

The first major contribution in the oilless breaker field was the development of the De-ion air breaker in 1928.[1, 2] Prior to this time, air circuit breakers had been used for many years with unquestionable success in lower-voltage circuits in which limited interrupting capacity was sufficient. The De-ion breaker, however, interrupted an arc in air using entirely new principles and so efficiently that it has been constructed for voltages up to 23 kv and for interrupting capacities as high as 750,000 kva at 15 kv or 1,500,000 kva at 23 kv. Twenty-three kv is sufficient for virtually all indoor applications in this country. This breaker is completely self-contained and operates without an auxiliary air system or the need of a replenishable interrupting fluid.

Greater interrupting capacities are continuously being required, and the economic range of the De-ion breaker will not prove adequate for all requirements. For higher interrupting capacities to 1,500,000 kva at 15 kv other forms of oilless breakers take on new attractions.

The departure from oil in Europe began with the introduction of both compressed-air and water breakers in 1929 and 1930.[3–6] The new trend was accelerated there because of the high price of oil and

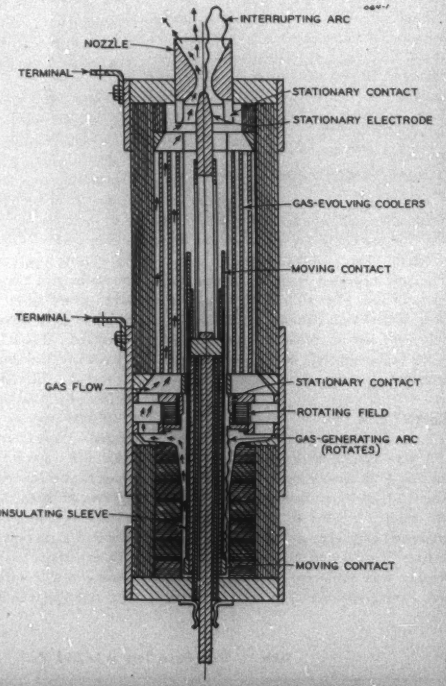

Figure 1. Self-generated-gas-blast circuit breaker (shown in open position)

Figure 2. Oscillogram of test on self-generated-gas-blast circuit breaker showing interruption of 30,000 amperes at 13.2 kv

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1. For all numbered references, see list at end of paper.

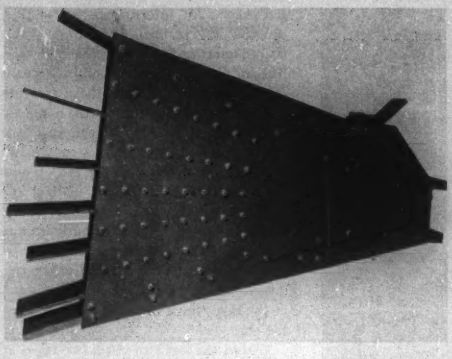


Figure 3. Experimental chute for compressed-air breaker

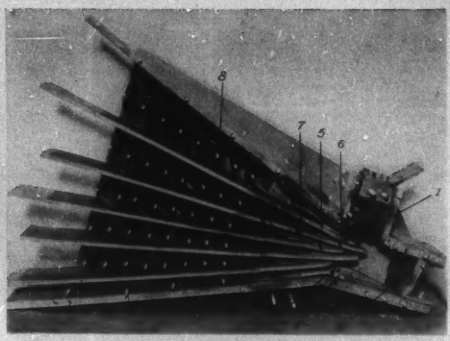


Figure 5. Experimental chute for compressed-air circuit breaker after extended series of tests

metals and because the limited capacities for which compressed air or water circuit breakers could then be built were sufficient to meet European requirements. Considerable development has been done in Europe with both types of breakers. The field of application of oilless breakers in Europe is becoming extensive and for some manufacturers is including the higher voltage and outdoor types.[7-9] In America, by contrast, the immediate demand is limited to indoor oilless breakers and although the European developments may influence the American trend, the more limited interrupting capacities which they find acceptable will not be sufficient to meet our requirements. This is especially true since European designs do not reach 1,000,000 kva, and American practice requires 1,500,000 kva or more at generator voltage.

Comparison of Principles of Air Circuit Interruption

In choosing a suitable operating principle for application to air circuit interruption, an experimental review of available methods was made. The results of this review will be described to present the background of reasons for the choice of interrupter finally reached.

Compressed-Air Arc Extinction

In Europe, variations of the nozzle type of interrupter have become most popular. They consist of an orifice through which an arc is drawn or blown and then subjected to a very intense longitudinal blast of air. For the lower ranges of current and at system capacities where the voltage recovery rate after arc extinction is not too great, this type of interrupter is quite satisfactory. As the current or voltage is increased the air requirements mount, until at 1,000,000 kva, pressures in excess of 200 pounds per square inch are required. The nozzle type of interrupter is, therefore, not appealing.

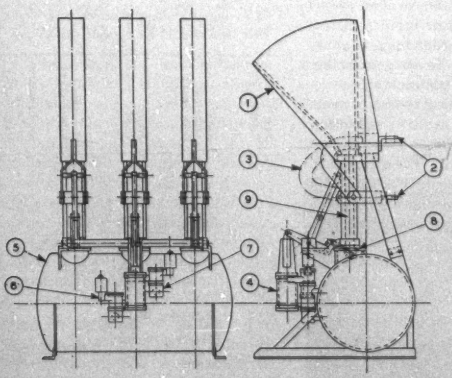


Figure 4. Compressed-air circuit breaker with vertical chute

1—Chutes
2—Terminals
3—Moving contacts
4—Operating cylinder
5—Storage tank
6—Closing valve
7—Opening valve
8—Air valve for chute
9—Insulated air tube

Self-Generated-Gas-Blast Breakers

In order to overcome the necessity of an external air-supply system, the blast of gas may be obtained by the decomposition of suitable materials. By selecting the proper material and arrangement, very high pressures of suitable gases may be obtained, and the energy to produce the gas pressure may be extracted from the arc itself during short circuit.

Boric-acid fuses and De-ion protector tubes are excellent examples of devices operating on this principle. In Europe, circuit breakers have been produced commercially where a synthetic resin is used for producing the gas blast.[12] Two self-generated-gas-blast breakers have been developed by the company with which the authors are associated—one utilizes boric-acid in close proximity to the arc-drawing contacts with suitable boric-acid-lined arc chutes into which the arc is driven by the expelled arc gases. The other is a two-arc interrupter as shown in figure 1. One arc is established through a conventional orifice and subjected to a longitudinal blast of gas in quite the same manner as used in continental compressed-air circuit breakers. The other arc is drawn in a space closely surrounded by gas-producing walls. This arc is not relied upon to supply interrupting ability except for low values of current, but to supply the gas blast for the first mentioned arc.

The interrupter consists of three essential elements—the lower part which houses one set of contacts, and the gas-forming elements; the central part which cools the hot gases and as a result of the

Figure 6. Magnetic oscillograms from table I

Fault current (amperes)—from left to right:
1,350 12,700 35,000 47,800 51,800

Recovery voltage (kv)—from left to right:
13.2 12.4 12.4 12.7 12.1

energy thus extracted, liberates more gas and eventually delivers the thoroughly cooled and deionized gas to the interrupting arc (which is located at the top of the interrupter) in such quantity and at sufficiently high pressure to handle very heavy currents.

Table I. Opening Tests on an Experimental Compressed-Air Circuit Breaker

13.2 Kv Initial Voltage Applied to a Single-Pole Unit of a 15-Kv Circuit Breaker, 60 Cycles

Test Number	RMS Amperes Interrupted	Arcing Time (Cycles)	Recovery Voltage (Kv)	Air Pressure in Tank (Lbs/Sq In.)
1	1,390	0.505	12.7	105
*2	1,350	0.35	13.2	105
3	2,080	0.20	12.8	150
4	2,620	0.20	13.0	150
5	2,660	0.45	13.0	150
6	4,220	0.20	12.7	150
7	5,180	0.25	12.9	150
8	4,950	0.35	12.9	150
9	10,400	0.45	12.8	150
10	10,000	0.15	12.5	150
11	7,900	0.40	12.8	150
*12	12,700	0.40	12.4	150
13	16,300	0.25	12.8	150
14	16,600	0.10	12.7	150
15	19,800	0.60	12.7	150
16	23,000	0.45	12.7	150
17	22,600	0.35	12.8	150
18	28,700	0.615	12.8	150
*19	35,000	0.505	12.4	150
20	40,600	0.6	12.5	150
*21	47,800	0.15	12.7	150
*22	51,800	0.25	12.1	150
23	32,700	0.15	12.4	150
24	31,900	0.15	12.3	150
25	41,400	0.35	12.3	150
26	30,650	0.505	12.4	150
27	33,800	0.70	12.4	125
28	23,000	0.75	12.5	125
29	20,650	0.60	12.6	125
30	27,800	0.25	12.4	125
31	23,800	0.75	12.4	125
32	36,700	0.40	12.2	125
33	43,000	0.40	12.2	125
34	33,100	0.505	12.4	125

* Magnetic oscillograms of these tests are shown in figure 6.

In this type of design the gas-forming parts must be shaped to supply sufficient gas for interruption at low currents without having excessive gas generation and pressure at high currents. Since the gas is obtained from solid surfaces in proximity to an arc, repeated operations produce erosion that affects the amount of gas generation and the interrupting characteristics. These considerations, together with other factors, discouraged further work on this type of construction.

The interrupter has handled currents up to 48,000 amperes at 7.6 kv and to 30,000 amperes at 13.2 kv as shown by the oscillogram in figure 2. The arcing time for the high values of current usually did not exceed two half cycles yet pressures as high as 1,000 pounds per square inch were recorded. While this pressure may seem high, extrapolation from compressed-air requirements for this type of nozzle interrupter are quite comparable. The ratings desired, however, appear to be beyond the capacity which can be reached with this principle.

Magnetically Produced Air Blast

For many years magnetic fields have been used to extinguish arcs by blowing them into some type of arc chute which lengthens and constricts the arc. Recently a new means of effecting interruption with a magnetic field has been described.[3,4] An interrupter of this type consists of parallel insulating plates spaced apart and slotted at the lower end. The arc is driven into this slot by means of a magnetic field. When the arc reaches the upper portion of the slot the magnetic field exerts a force on the electrons in the gas stream and gives them a component of velocity transverse to the arc. These electrons in turn bombard neutral gas particles, with the final result that a blast of gas is caused to flow upward through the arc path. When current zero is reached this blast of gas effectively introduces a strong deionizing action at the end of the slot, which effectively extinguishes the arc.

Within the last two years two types of lower-voltage breakers have been developed using this interrupting principle. The first type was for 600 volts and below and the second for potentials of 2,500 and 5,000 volts. The lower-voltage devices have interrupted currents as high as 120,000 amperes and the 2,500-volt interrupter satisfactorily clears currents up to 50,000 amperes.

The effectiveness of this principle is not sufficient for the interruption of currents as high as 60,000 amperes at 15,000 volts.

Compressed-Air Interrupter

A more effective air stream can obviously be produced by utilizing compressed

Table II. Opening Tests on an Experimental Compressed-Air Circuit Breaker

13.2 Kv Initial Voltage Applied to a Single-Pole Unit of a 15-Kv Breaker, 60 Cycles

Test Number	RMS Amperes Interrupted	Arcing Time (Cycles)	Recovery Voltage (Kv)	Air Pressure in Tank (Lbs/Sq In.)
1	1,370	0.45	13.1	150
2	1,310	0.45	13.2	150
3	2,740	0.35	13.1	150
4	3,020	0.15	13.2	150
5	3,920	0.35	13.1	150
6	4,550	0.45	13.1	150
7	4,950	0.35	13.0	150
8	10,600	0.35	12.8	150
9	10,700	0.65	13.0	150
10	11,100	0.40	13.0	150
11, 12, 13	Approximately 12,000	No oscillogram		150
14	27,800	0.35	12.7	150
15	23,800	0.45	12.7	150
16	23,400	0.35	12.6	150
17	34,600	0.35	12.6	150
18	26,600	0.35	12.4	150
19	23,900	0.45	12.3	150
20	39,800	0.65	12.2	150
21	50,100	0.60	12.2	150
22	31,000	0.50	12.2	150
23	40,000	0.60	12.4	150
24	30,200	0.50	12.3	150
25	51,800	0.85	12.3	150

Table III. Opening and Closing-Opening Tests on an Experimental Compressed-Air Circuit Breaker

13.2 Kv Initial Voltage Applied to a Single-Pole Unit of a 15-Kv Circuit Breaker

Test Number	Operation	RMS Amperes Interrupted	Arcing Time (Cycles)	Recovery Voltage (Kv)	Air Pressure in Tank (Lbs/Sq In.)
1	O	1,380	1.1	13.0	150
2	O	1,280	0.5	13.3	150
3	O	2,890	0.3	13.2	150
4	O	3,440	0.3	13.2	150
5	O	2,690	0.3	13.1	150
6	O	4,660	0.2	13.2	150
7	O	4,460	0.3	13.1	150
*8	O	6,200	0.4	13.1	150
9	O	9,000	0.9	13.0	150
10	O	7,500	0.5	13.0	150
11	O	7,000	0.2	12.6	150
12	O	16,000	0.3	12.6	150
*13	O	15,800	0.3	12.7	150
14	O	9,600	0.7	12.8	150
15	O	20,600	0.6	12.4	150
16	O	23,400	0.6	12.6	150
17	O	22,800	0.7	12.2	150
*18	O	29,000	0.7	12.4	150
*19	O	40,000	0.4	12.6	150
20	O	40,000	0.4	12.5	150
21	O	44,400	0.4	12.0	150
22	O	44,400	0.6	12.5	150
23	CO	1,270	0.6	13.0	150
24	CO	1,280	0.7	13.1	150
25	CO	2,650	0.5	13.0	150
26	CO	2,530	0.5	13.0	150
27	CO	2,570	0.5	13.0	150
28	CO	4,320	0.6	13.0	150
29	CO	3,980	0.6	13.0	150
30	CO	4,260	0.6	13.0	150
31	CO	7,520	0.6	12.8	150
32	CO	7,520	0.6	12.8	150
33	CO	7,450	1.2	12.8	150
34	CO	11,300	0.3	12.6	150
35	CO	11,500	0.7	12.4	150
36	CO	17,000	0.3	12.0	150
37	CO	Approx. 20,000	No oscillogram	No oscillogram	150
38	CO	Approx. 20,000	No oscillogram	No oscillogram	150
39	CO	20,800	0.5	11.4	150
40	CO	Approx. 25,000	No oscillogram	No oscillogram	150
†41	CO	25,000	0.8	11.2	150
42	CO	27,500	0.6	11.3	150

*Magnetic oscillograms and cathode-ray oscillograms of these tests are shown in figures 7 and 8 respectively.

†Magnetic oscillogram of this test is shown in figure 9.

air in the type of arc chamber just described. In this case the magnetic field is no longer necessary. Tests were made with this structure which indicated greatly increased interrupting capacity. An external air-supply system must be provided of course, but in view of the extremely high interrupting ratings which can be achieved in very small space, the use of compressed air in conjunction with an arc chamber of the type described appeared to be the most feasible method of proceeding toward the design of a breaker having sufficient interrupting capacity to meet all indoor requirements. A comparison of the interrupting ability of a compressed-air device built in this manner, with known types of compressed-air breakers utilizing nozzles for interruption, indicated that an air stream perpendicular to the arc path in conjunction with insulating plates was much superior.

The contacts and surrounding walls are arranged so that the arc is blown by the air stream from its point of inception against suitable insulating splitters. There the arc remains practically stationary and substantially perpendicular to the gas blast throughout the arcing period. During this time the gas is allowed to escape around the sides of the arc, freely enough to prevent building up of pressure sufficient to interfere with the continuity of the arc stream and at the same time sweeps the excess ionization from around the arc out into the space beyond the splitters. Thus, as the current zero approaches, the residual ionization associated with previous high current has been removed without high arc voltage, and the time between current zero and restored voltage becomes adequate for interruption even though the voltage recovery rate is high.

The next important requirement is to cool and deionize the gases sufficiently before allowing them to escape beyond the splitters, to prevent flashover on the outside. Further cooling is necessary for the higher kilovolt-ampere ratings to prevent excessive external demonstration. Both of these problems are solved by suitable coolers and mufflers described later.

Aside from the considerations of intimate association of the gas pressure, arc behavior, and splitter performance, there are other practical reasons that favor the cross-blast type of construction over the longitudinal blast. These considerations are: (1) the ability with a blast of air directed at right angles to the direction of contact separation to sweep the arc quickly from the contacts, thereby permitting both main and arcing contacts to remain in the chute; (2) the ability to increase the cross-sectional area of the main current-carrying member within wide limits, without affecting any of the parts

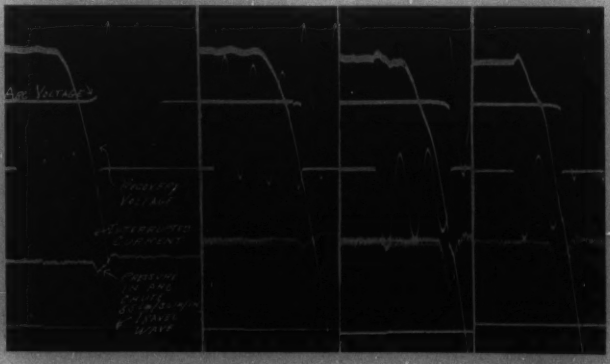
Figure 7. Magnetic oscillograms from table III

Fault current (amperes)—from left to right:

6,200 15,800 29,000 40,000

Recovery voltage (kv)—from left to right:

13.1 12.7 12.4 12.6



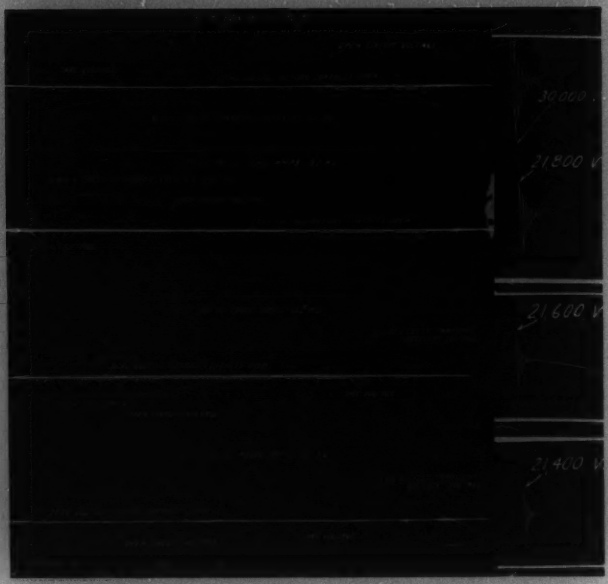


Figure 8. Cathode-ray oscillograms corresponding to those of figure 7

involved in arc extinction. These two factors simplify the construction of the breaker and are of particular importance on the heavier current units of the power-house class.

An experimental arc chute as shown in figure 3 was built along these lines for test. This form of interrupter is flexible and can be adapted to a breaker design as shown in figure 4, or it can be disposed horizontally, depending on the application requirements. Figure 5 shows an open view of this same chute after having successfully interrupted 45 short circuits at currents varying from 1,000 to 50,000 amperes at 13,200 volts as listed in table III. During the tests the interrupter was in a horizontal position on the breaker. After these tests the contacts were found to be in excellent condition. There was some erosion of the splitters as may be seen, however, this erosion was not sufficient to render them unfit for further service.

Referring to figure 5, (1) is the stationary contact from which the moving contact (2) is withdrawn pulling an arc along the path (3). This arc under the action of a blast of air from the orifice (4) is driven into intimate contact with the splitters (5) along the path (6). The arc gases expelled from the throat impinge first on the copper buffer plates (7) which perform the first cooling and deionizing action on the arc gases. The partially cooled and deionized gases then pass on through the cooling and diffusing screens (8) that cool and diffuse the arc gases effectively preventing external flame and disturbance.

Test Results

Tables I, II, and III show the results of three typical series of single-phase tests using the arc chute shown in figure 3. During these tests the pressure in the tank varied between 105 and 150 pounds per square inch. The pressure in the arc chute was measured with an instantaneous recording telemeter. This pressure was negligible except during the arcing period. The effect of the arc acting as an impediment to the free escape of air caused a temporary build-up in pressure back of the arc which in some cases almost equalled the tank pressure.

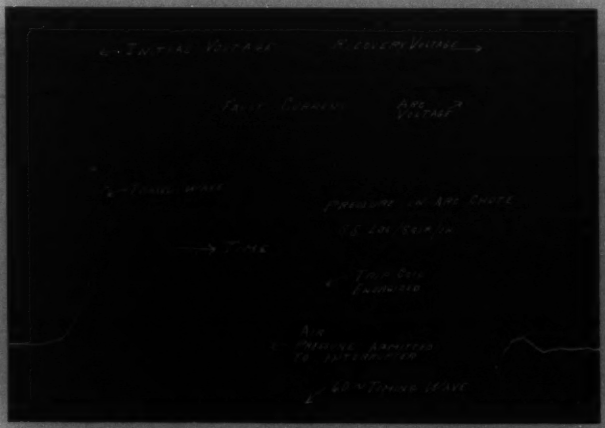
The arcing time was generally less than that corresponding to one-half cycle of current. Sometimes when the current was highly asymmetrical arcing would continue over one entire current loop which would lengthen the time to over one-half cycle. The breaker rarely passed up an opportunity to clear if the contacts were parted one-half inch or more when a current zero occurred.

Tables I and II show currents ranging from approximately 1,000 amperes to 52,000 amperes with 13.2 kv across a single-pole unit.

Figure 6 shows typical oscillograms taken from table I at 1,000, 12,700, 35,000, 48,000, and 53,000 respectively. The oscillograms from table II are all very similar to the ones shown in figure 6.

Table III shows a series of 45 tests covering the same current range. On some of these tests cathode-ray oscillograms were obtained, these together with the magnetic oscillograms shown in figures 7 and 8 are of interest in proving that the operation of the breaker is consistently fast and dependable even on a circuit with a natural oscillatory frequency of 28,300

Figure 9. Typical oscillogram of closing-opening tests



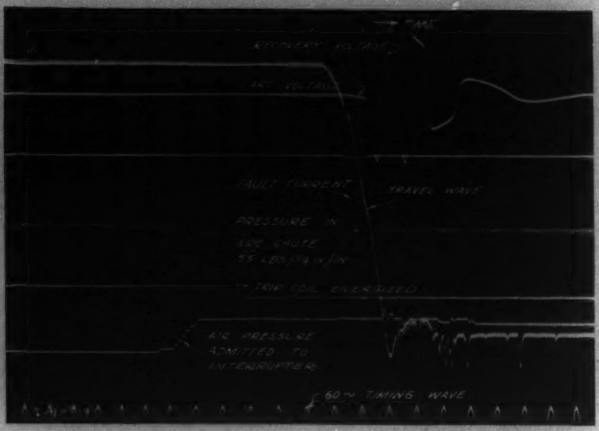


Figure 10. Oscillogram showing interruption of 65,300 *rms* amperes at 13.2 kv, single phase

cycles per second, and a circuit transient recovery voltage rate of 2,200 volts per microsecond. On this circuit the test transient recovery voltage rate was 1,380 volts per microsecond as shown for test 19. The transient recovery voltage rate is given as the slope of the tangent to the recovery voltage wave. It is obtained by dividing the maximum voltage by the time of one-half cycle of natural frequency and multiplying by 1.15. This method is used because the recovery transient consists essentially of a single sinusoidal component.

Figure 9 shows a typical closing-opening test. The ability of this breaker to close in on high current without showing any evidence of distress is noteworthy.

Figure 10 shows an oscillogram of the highest current interrupted. It was obtained during a fourth run similar to the one shown in the tables. This film shows satisfactory interruption of 65,300 amperes rms at 13.2 kv, single phase.

These interruptions were obtained with negligible external demonstration in the form of ionized flame. Noise accompanying the interruption is held to acceptable limits by the arc chamber design as shown. A particularly significant feature of all tests is the high mechanical speed of the breaker contacts. It is possible to separate these contacts two inches in one-half cycle. This high speed is the effect of properly using an air mechanism to operate the breaker. Very high opening and closing forces can be exerted on the piston which is moved in the cylinder by the compressed air itself to actuate the contacts. Springs which would give comparable operating speeds would represent a nearly impossible mechanical design. It is also a simple matter properly to control the air cylinders to stop the contacts and their associated operating rods without undue jar on rebound at the end of the opening stroke.

A compressed-air interrupter of the type described appears to be particularly rugged and to handle repeatedly interruption of the highest currents without excessive damage. The low energy input into an interrupting chamber of this type which is the function of careful design to minimize the arcing time, to approximately one-half cycle, and to keep the arc drop low during the arcing period, is primarily responsible for reliability without excessive erosion.

Table IV. Summary of Information From Cathode-Ray Oscillograms

Test Number	Frequency (Cycles/Sec)	Crest Voltage	Test Transient Recovery Voltage Rate (Volts/Microsec)	Circuit Transient Recovery Voltage Rate (Volts/Microsec)
*8	13,500	30,000	920	1,050
*13	23,500	21,800	1,150	1,820
*18	24,400	21,600	1,210	1,890
*19	28,300	21,400	1,380	2,200

* Magnetic oscillograms and cathode-ray oscillograms of these tests are shown in figures 7 and 8 respectively.

Conclusions

The search for improved forms of dry-type circuit interrupters suitable for interruption of 1,500,000 kva, at 15,000 volts, indicates that the use of a compressed-air stream transverse to an arc is the most effective. Currents as high as 65,300 amperes have been interrupted at 13,200 volts single phase with a contact separation of approximately two inches, which can be mechanically obtained in one-half cycle. A breaker utilizing these new principles of interruption makes possible new standards of system protection because of its high operating speed, complete freedom from oil and associated fire hazard, and remarkably high interrupting capacity in terms of the space required by the breaker.

Bibliography

1. Theory of the De-ion Circuit Breaker, **J. Slepian.** AIEE Transactions, volume 48, 1929, page 523.

2. Structural Development of the De-ion Grid Circuit Breaker up to 15,000 Volts, **R. C. Dickinson and B. P. Baker.** AIEE Transactions, volume 48, 1929, page 528.

3. Hochleistungsschalter ohne Oel, **J. Biermanns.** *E.T.Z.*, July 25, August 1, 1929, pages 1073–9, 1114–19.

4. Hochleistungsschalter ohne Oel, **J. Biermanns.** *E.T.Z.*, February 27, 1930, pages 299–304.

5. Present Tendencies in the Construction and Application of High-Voltage Circuit Breakers, **Arnold Roth.** *Bulletin* de la Société Française des Electriciens, October 1930, pages 1030–56.

6. Der Expansionsschalter, **F. Kesselring.** *E.T.Z.*, April 3, 1930, pages 499–508.

7. A.E.G. Freistrahl-Druckgasschalter, **G. Brockhaus.** *A.E.G. Mitteilungen*, December 1937, pages 446–50.

8. The Brown Boveri Air-Blast High-Speed Circuit Breaker. *Brown Boveri Review*, November 1935, page 199.

9. Compressed-Air Circuit Breakers. *Brown Boveri Review*, March 1939, pages 55 to 68.

10. The Expulsion Fuse, **J. Slepian and C. L. Denault.** AIEE Transactions, volume 51, March 1932, page 157.

11. The Boric-Acid Fuse, **A. P. Strom and H. L. Rawlins.** AIEE Transactions, volume 51, 1932.

12. Improvements in Construction of Gas-Blast Circuit Breakers, **J. Biermanns.** *E.T.Z.*, volume 59, February 1938, page 165.

13. A New High-Capacity Air Breaker, **L. R. Ludwig and G. G. Grissinger.** AIEE Transactions, volume 58, August 1939.

14. Magnetic De-ion Air Breaker for 2,500–5,000 Volts, **L. R. Ludwig and R. H. Nau.** AIEE Transactions, volume 59, 1940 (September section), pages 518–22.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

What Wood May Add to Primary Insulation for Withstanding Lightning

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ON power-transmission lines, wood, serving certain structural functions, simultaneously may provide supplementary insulation against lightning if properly chosen and applied. However, to sustain the power-frequency voltage, adequate primary insulation in the form of porcelain insulators or the like is essential.

These facts have been rather well known for some time, but in degree the ability of wood to withstand lightning has not been thoroughly determined. In the laboratory study described two years ago,[1] this phase was partially covered. It is the purpose of this paper to describe the results of a testing program in the same laboratory, treating of all factors which it was felt could affect the lightning or impulse strength of wood.

Nothing relating to the 60-cycle strength of wood will be given here, for, as outdoor insulation against sustained power-frequency voltage, wood, with its internal moisture, is generally considered quite ineffective. For briefly applied surges, such as lightning or switching transients below flashover voltage, the moisture content is not damaging to the wood. However, for sustained 60-cycle voltages, the electrolytic nature of the moisture allows leakage currents which ultimately cause burning and charring of the wood. As intimated above, it is the purpose of effective primary insulation in series with the wood to check this action.

It will be shown below that the degree to which wood will supplement porcelain against lightning depends almost entirely upon its length and internal moisture, and little upon its creosoting treatment, cross section, or kind. Considerable test data were obtained in this study and numerous curves and tables developed directly therefrom. In the interest of brevity and clarity, practically all of these original curves are omitted here and only so-called "working curves" which were derived from the originals, are included. Accordingly, most of the kilovolts of insulation plotted involve actual supplementary wood insulation values to be added directly to the impulse kilovolts of the associated insulators. Likewise, ratios and percentages are used for expressing the effects of certain wood properties upon the insulation strength of wood.

Paper 40-25, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 8, 1939; made available for preprinting December 14, 1939.

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Crossarm and pole specimens used in many of the tests were from the Georgia Power Company, Mississippi Power Company, New England Power Service Corporation, and Ohio Power Company. The special creosoted planks with known moisture contents were prepared by the Wood Preserving Corporation under the direction of W. P. Arnold.

1. For numbered reference, see end of paper.

Nature of Test Equipment and Data

The various stages of the 3,000,000-volt impulse generator at the Barberton high-voltage laboratory of the Ohio Brass Company were used in these tests. The generator itself was always adjusted for the standard $1^1/_2 \times 40$-microsecond wave.

For tests on the wood specimens alone, voltage was applied between braided metallic bands tightly wrapped about the wood. This was felt to simulate electrically most hardware conditions in service. In the case of a combined insulator and wood test, voltage was applied to the conductor attached to the insulator while the braided band was adjusted along the wood member and grounded. For all tests, the specimens themselves were suspended at sufficient distances from nearby grounded objects to eliminate interference with the electrostatic fields being studied.

On practically all specimens, complete volt-time curves were taken with both positive and negative polarities, cathode-ray oscillograms being secured for every impulse. To allow compactness of presentation, however, curves are given showing flashover voltages at only the two-microsecond and "critical" (formerly termed "50-50" or "minimum") points. It is felt that the two-microsecond point represents direct-stroke conditions of average severity while the critical flashover values allow computations for induced voltages and other long-wave conditions.

Flashover Voltages of Structure Parts

As pointed out above, any structure design computations made from information in this paper require the addition of the supplementary wood values from certain curves to actual insulator flashover values. Figures 1 and 2 provide the necessary flashover data of a pin-type and a suspension insulator for use in typical examples in this paper.

Figure 3 affords rod-gap data for assisting in designing so-called "horn gaps" for wood members. As will be shown by later examples, such gaps can be made to protect parallel crossarm or pole paths if adjusted to have lower flashover strengths. The proper crossarm and pole data for this comparative study is provided in the curves of figures 4 and 5. No measurable difference was found for surges of the two polarities so that the curves of these two figures represent the average of all data. The data from figures 4 and 5 are only for comparison with other parallel flashover paths, such as air gaps or insulators, and they are not to be added to other insulation in series.

Flashover Voltages Added to Porcelain by Wood

In figures 6 to 9 are given the supplementary impulse insulation strengths afforded porcelain insulators by different lengths of various wood members. For each case the flashover data from the curve *must be added* to the corresponding flashover data of the insulator chosen in order to have the total lightning or impulse strength of the combination. The supplementary insulation values which

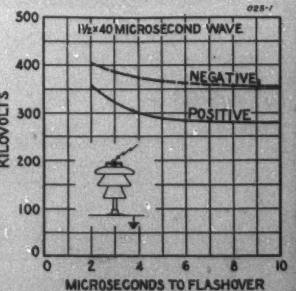


Figure 1. Impulse volt-time curve of 69-kv pin-type insulator

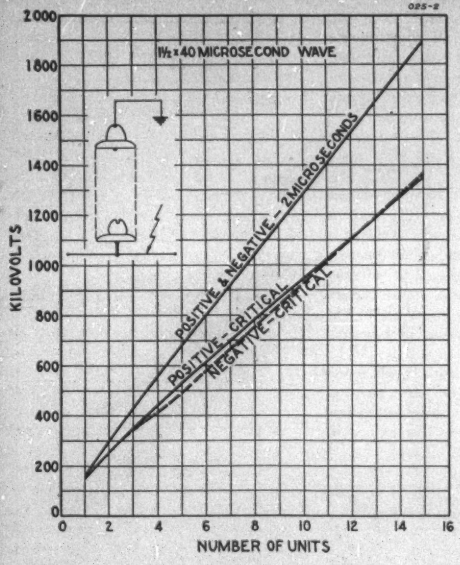


Figure 2. Impulse flashover voltages of 10 by 5³/₄-inch suspension insulators

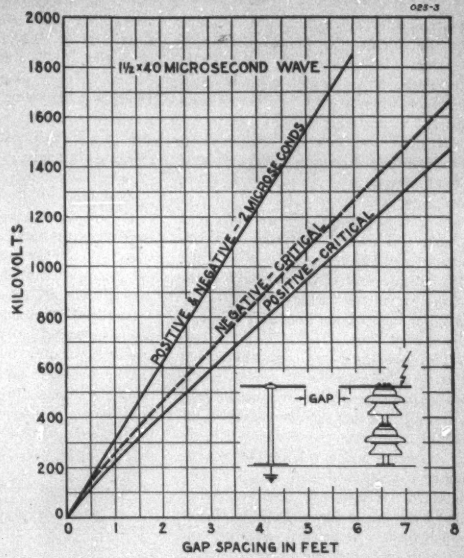


Figure 3. Impulse flashover voltages of rod gaps

pole sections add to pin-type crossarm combinations (figure 6) are shown in figure 10.

All wood insulation values in figures 4 to 10 inclusive, except for cedar and newly creosoted pine poles in figure 5, are based on tests on wood with an average moisture content of about 15 per cent.

Data, described in the paper referred to above,[1] indicated that the total insulation strengths of insulator and wood combinations could be calculated by multiplying the sum of the individual flashover strengths by certain constants. Subsequent and more numerous data, however, tend to prove that more accurate calculations can be made by the use of curves such as given in figures 6 to 10. Also, an analysis of the electrostatic conditions involved tends to bear this out. For example, the effect of changing the constants of one member, such as by lengthening indefinitely the crossarm supporting the insulator, cannot always allow the actual flashover voltage to be the same percentage of the sum of the insulator and arm flashover voltages.

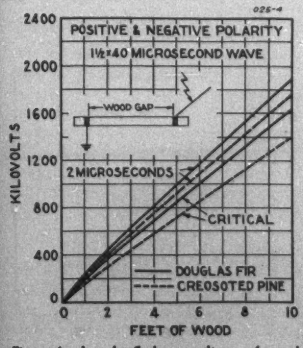


Figure 4. Impulse flashover voltages of wood crossarms

Factors Influencing Impulse Insulation Values

Cross Section

Previously published data[1] indicated that the impulse flashover voltage of wood decreases as its cross-sectional area is increased. This subsequent investigation, however, shows that certain other factors have greater effects and that cross-sectional area is of secondary importance.

Another related factor which may affect the flashover voltage is the distribution of the wood cross section, as exemplified by solid and multiple-plank crossarms with equal cross-sectional areas. The ratios in figure 11 are the result of flashover tests upon a number of combinations of insulators and creosoted pine timbers. The latter were first tested as six by eight-inch solid crossarms and then sawed and retested as three by eight-inch double plank crossarms. The average ratio for the positive critical flashover is about 0.96 and that for the negative is about 1.02, indicating that as far as the impulse flashover voltage is concerned, there is little to be gained by the choice of one type of construction over the other. However, a definite advantage is gained with the double-plank crossarm in that a lightning stroke damages only one member and leaves the other intact for supporting the line.

Creosote Treatment

Since wood used in power-line structures may be creosoted, it is desirable to know the effects on flashover voltages of the various kinds of creosote, degrees of retention, and methods of treatment. A number of flashover tests were made on three-foot sections of newly creosoted green pine crossarms in series with three 10 by 5³/₄-inch suspension insulators. Light creosote with retentions of eight and ten pounds per cubic foot of wood, and heavy creosote with a ten-pound retention were used in the preparation of the test specimens. Results of these tests, some of which are shown in figure 12, indicate

that no appreciable difference is caused by the various grades of creosote or retentions. Still other tests indicate that the flashover voltage of wood is about the same when treated by different commercial creosoting processes.

In order to study the relative flashover voltages of creosoted and untreated wood, several pairs of specially prepared dry pine timbers were tested. Each pair was obtained from the same original plank, and only one of each pair was creosoted. The results, shown in figure 13, indicate that creosoting reduces the flashover voltage of the combination of wood and suspension insulators only 6 or 7 per cent.

Pine used in power-line structures is usually creosoted while Douglas fir may be used either untreated or creosoted. Various tests show that there is no appreciable difference between the flashover voltages of untreated and creosoted Douglas fir, either by itself or in combination with insulators. Accordingly, all of the flashover curves from figures 4 to 10 inclusive which include Douglas fir may be used for both creosoted and untreated wood.

Rain

Since lightning is usually accompanied by rain, it seemed desirable to know the effects of rain on the impulse insulation of wood. It had been reported previously[1] that rain may reduce the impulse flashover of wood structures by as much as 50 per cent.

In order to determine whether such a reduction is caused by rain in the air, and on the insulator and wood surfaces, or by the moisture penetration into the wood, a special series of tests was made. A dry Douglas-fir crossarm was completely covered with several coats of lacquer to keep out moisture and subjected to dry and wet flashover tests. The wet tests were made using standard AIEE rain (precipitation 0.2 inch per minute; resistivity, 7,000 ohms per inch cube). Similar tests were made upon unlacquered Douglas fir, red elm, and red oak, these woods being chosen because of their dense structure. The results of these tests are presented in figure 14 as the ratio of wet to dry flashover voltage.

As shown, the critical flashover voltages of the unlacquered woods are reduced on the average to about 65 or 70 per cent of the dry flashover values, and the two-microsecond to about 75 or 80 per cent. Those of the lacquered crossarms showed a change of less than 10 per cent. The ratios exceeding unity for the lacquered arm are probably the result of the increased dielectric strength of air under rain conditions. Since the flashover value of each unlacquered crossarm was reduced considerably by the rain while

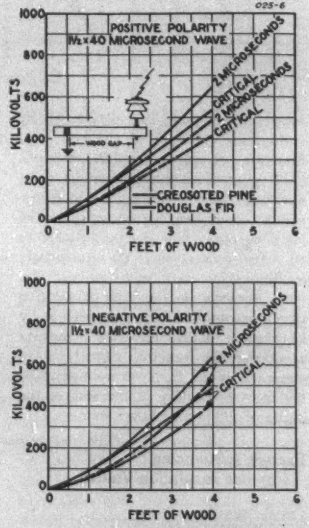


Figure 6. Impulse insulation added to pin-type insulators by crossarms

that of the lacquered arm was practically unchanged, it seems logical to presume that the penetration of moisture into the wood is the fundamental cause of the observed reduction.

The effect which the duration of rain has upon the impulse insulation of wood and insulators is indicated in figure 15. The tests here were made on four-unit insulator strings suspended from four-foot sections of both untreated Douglas-

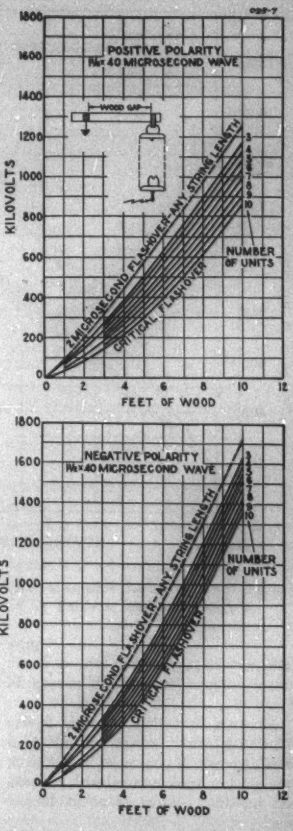


Figure 7. Impulse insulation added to suspension-insulator strings by wood crossarms (creosoted pine or Douglas fir)

fir and creosoted-pine crossarms. The greatest reduction in flashover voltage seems to occur within a very few minutes after the rain starts, negligible change resulting thereafter.

While rain definitely reduces the impulse insulation of wood structures, there is always a chance that the wood may not be wet at the instant it is subjected to a lightning voltage. Furthermore, the standard rate of precipitation used in these tests far exceeds the usual rate of natural storms. Accordingly, it is possible that the flashover voltage may not decrease as rapidly as indicated in figure 15. In general, therefore, the actual reduction factor for rain for a given condition appears to be a matter of probability.

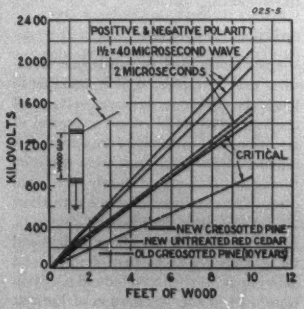


Figure 5. Impulse flashover voltages of wood poles

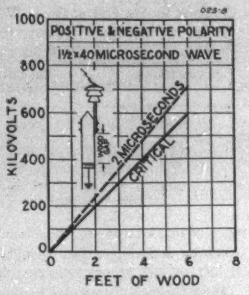


Figure 8. Impulse insulation added to pin-type insulator by pole sections (creosoted pine)

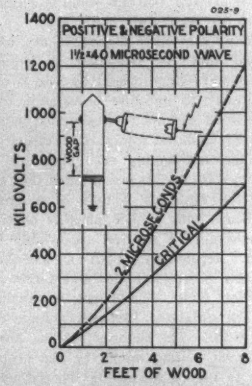


Figure 9. Impulse insulation added to suspension-insulator strings by pole sections (creosoted pine)

MOISTURE CONTENT

The results of the various rain tests indicated that moisture penetration into the wood was responsible for the reduction of its impulse flashover voltage. Furthermore, it had been observed that green wood has a lower flashover voltage than equivalent dry wood. Accordingly, it seemed desirable to conduct a systematic investigation of the effects of internal moisture upon the impulse flashover voltage of wood.

Figure 16 gives results of flashover tests on four-unit strings of 10 by 5¾-inch insulators suspended from four-foot sections of creosoted-pine crossarms with moisture contents varying from 12 to 93 per cent. Similar tests were made on the same crossarms without insulators. Other tests were also made on similar arrangements of untreated Douglas-fir crossarms with controlled moisture contents.

The results of this study are presented in figure 17 as the ratio of the flashover voltage at any moisture content to the flashover voltage at 15 per cent moisture content. The latter is usually considered the average for dry wood in moisture equilibrium with the atmosphere.

When wood with internal moisture is placed under electrical stress, electrolytic conduction may occur within it. This might influence the electrostatic field of the wood, and therefore, its flashover voltage in combinations with insulators. The degree to which this would take place may vary with the different woods because of their internal cellular structures. This may account for the difference in behavior of the several woods in the curves of this paper. The amount of voltage reduction introduced by internal moisture also may be dependent upon the duration of the transient, as

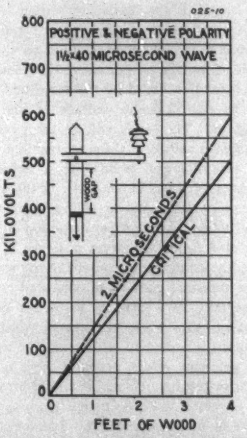


Figure 10. Impulse insulation added to combinations of pin type with crossarm by sections of poles (creosoted pine)

time is required for electrolytic conduction. This may be a possible explanation of why the two-microsecond flashover voltage (figure 17) is influenced less than the critical by the internal moisture.

From figure 5, the critical flashover voltage of eight-foot sections of newly creosoted pine poles is about 720 kv while that of old poles is about 1,200 kv. The ratio of these flashover voltages is about 0.60, which corresponds to a moisture content of about 33 per cent on the creosoted pine curve in figure 17. The newly creosoted pine poles were presumably green wood while the old poles were fairly dry, having been in service for several years. A moisture content of 33 per cent is a reasonable value for green wood and, accordingly, it would seem that the curves shown for crossarms (figure 17) may be satisfactory for poles as well.

As shown by the curves of figure 17, an immediate increase of impulse insulation strength may be secured by predrying wood to its equilibrium value before it is installed on transmission-line structures. On the other hand, the insulation value of green wood will increase gradually to the same level as its internal moisture approaches equilibrium with that of the atmosphere. Accordingly, the choice between predried and green wood appears to be a matter of economics.

Spread of Data

All curves presented in figures 4 to 10 inclusive represent the average of numerous data points, which lie within ±15 to ±20 per cent of the average. These rather wide limits are believed to be the result of inherent structural variations within the wood itself which influence its impulse flashover voltage.

Critical flashover tests were made on a group of about 60 newly creosoted pine poles, each pole being subjected to the same test procedure. These flashover voltages ranged from 490 kv to 836 kv, averaging about 675 kv. The spread of data with respect to the average was as follows:

Spread of Data in Per Cent	Number of Test Values Included	Per Cent of Total Number of Test Values Included
± 5	25	41
±10	41	67
±15	48	79
±20	56	92
±25	60	98
±28	61	100

In the above table 92 per cent of all

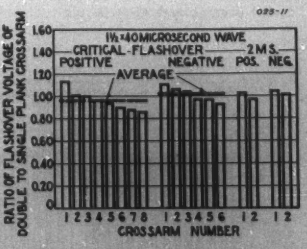

025-11
1½×40 MICROSECOND WAVE
CRITICAL-FLASHOVER
2 M.S.
POSITIVE
NEGATIVE POS. NEG.
AVERAGE
RATIO OF FLASHOVER VOLTAGE OF DOUBLE TO SINGLE PLANK CROSSARM
1 2 3 4 5 6 7 8 1 2 3 4 5 6 1 2 1 2
CROSSARM NUMBER

Figure 11. Comparison of impulse flashover voltages of single- and double-plank crossarms with pin-type and suspension insulators

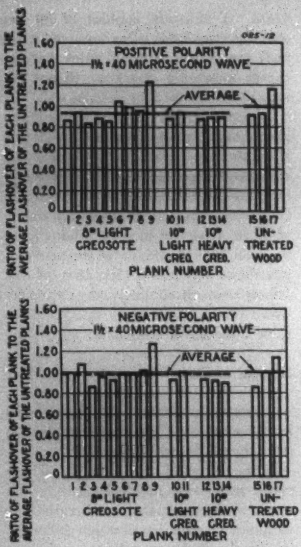


Figure 12. Effects of various creosotes and retentions upon impulse flashover voltages of pine crossarms with suspension-insulator strings

the tests are included in a ±20 per cent spread while a ±25 per cent spread includes all but one test. Similar distributions of test values would probably be found for various combinations of insulators and wood, although the spread in the above tabulation of green-pole data is probably as great as would ever be found.

When the curves of figures 4 to 10 inclusive are used for estimating the flashover voltage of a given structure, the result obtained will represent the average flashover voltage of a large number of similar structures. For example, if tests were made on 100 similar structures the average of these test values would probably agree quite closely with the estimated average and 90 to 95 per cent of these tests would lie within a ±20 per cent band.

Table I. Protective Horn Gaps on Creosoted Pine Crossarms for Six Feet of Green Wood

	Positive		Negative	
	Critical	Two-Microsecond	Critical	Two-Microsecond
Flashover of dry wood (figure 4) in kv	840	1,080	840	1,080
Assumed moisture content in per cent	35	35	35	35
Reduction factor (figure 17)	0.57	0.77	0.57	0.77
Flashover of green wood in kv	480	830	480	830
Rod gap having flashover equal to that of green wood (figure 3) in inches	0.29	832	25	32

Application of Curves to Typical Problems

General Procedure

By means of the curves in this paper it is possible to estimate the various impulse flashover voltages of numerous combinations of insulators and wood.

The first step is to obtain the flashover voltage of the insulator, either from figures 1 or 2 or from other reliable sources. The second step is to determine from the proper curve the kilovolts of insulation *added* by the wood and *add* it to the flashover voltage of the insulator. The result will be the average flashover voltage of the given combination of insulator and wood with a moisture content of about 15 per cent. If the wood is green, this flashover voltage should be multiplied by the proper reduction factor, selected from the curves of figure 17 for the known moisture content of the wood. The moisture content of creosoted green pine may vary from 30 to 60 per cent, and in cases where the actual moisture content is unknown, an average value of 35 per cent would probably give satisfactory results. Green fir and cedar can be expected to be no higher than 35 per cent in moisture content. Incidentally, this may account for the flashover voltage curve of new cedar poles in figure 5 being higher than that of new creosoted pine poles.

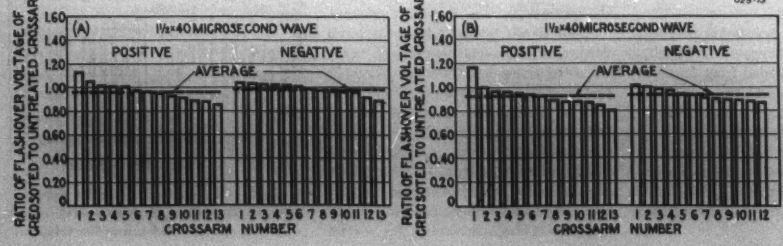
In case the flashover voltage under rain conditions is desired, the flashover voltage, estimated for the combination of insulator and dry wood, should be multiplied by the proper reduction factor. From the results presented in figures 14 and 15, it would appear that a factor of 0.65 to 0.70 for critical flashovers and 0.75 to 0.80 for two-microsecond flashovers of either polarity would be suitable reduction factors due to the rain.

Tests previously discussed have indicated that the reduction in impulse flashover voltage caused by rain is due primarily to moisture penetration into the wood and not to a reduction in the impulse flashover voltage of the insulators or the surrounding air. Therefore, it seems a reasonable presumption that the impulse flashover voltage of a green crossarm with a high moisture content should not be lowered appreciably by rain. Accordingly, both a moisture-content reduction factor and a rain reduction factor should not be applied to the estimated flashover voltage for dry wood. The factor giving the lower flashover voltage would be the proper one to use in estimating the flashover voltage under adverse conditions.

Examples

The following examples are presented to illustrate several applications of the curves in this paper and to demonstrate the agreement of estimated with actual test values.

Figure 13. Effect of creosote treatment of wood upon its impulse flashover voltage with and without insulators



(*A*)—Five feet of creosoted pine crossarm only

(*B*)—Five feet of creosoted pine crossarm with five 10 by 5¾-inch suspension insulators

Example 1. In this example the dry and wet impulse flashover voltages of a 69-kv pin-type insulator and four feet of creosoted pine crossarm are determined.

Positive Critical	
Flashover of insulator (figure 1)	260 kv
Insulation added by wood (figure 6)	410 kv
Estimated flashover, dry	670 kv
Actual test value, dry	690 kv
Ratio of estimated to actual	0.99
Reduction factor due to rain	0.65
Estimated flashover, wet	435 kv
Actual test value, wet	445 kv
Ratio of estimated to actual	0.98

The negative critical, and positive and negative two-microsecond flashover voltages may be estimated in a similar manner.

Example 2. In this example the estimated voltage is for phase-to-phase flashover between conductors supported by two 33-kv pin-type insulators on the same 22-inch creosoted pine crossarm with two wood sections between phases such as results from the use of metal crossarm braces. When an impulse is applied between conductors, each combination of insulator and wood section is subjected to an impulse of opposite polarity from the other. Accordingly, the procedure is to estimate the positive and negative critical flashover voltages for one insulator and wood section, add these two estimates together, and multiply by a factor of 0.85. The latter is chosen because tests have indicated that when two such combinations are placed in series the resulting flashover voltage averages about 0.85 of the sum of the flashover voltages of the individual combinations. Similarly, a factor of 1.00 has been determined for the two-microsecond flashover. There is evidence that the same procedure will prove satisfactory for strings of suspension insulators in place of pin type.

Critical Flashover		
Positive critical flashover of pin type	200 kv	
Insulation added by wood (figure 6)	165 kv	
Total, positive		365 kv
Negative critical flashover of pin type	255 kv	
Insulation added by wood (figure 6)	130 kv	
Total, negative		385 kv
Sum, positive and negative		750 kv
Reduction factor	0.85	
Estimated flashover, positive or negative	640 kv	
Actual test value, positive	620 kv	
Ratio of estimated to actual, positive	1.03	
Actual test value, negative	650 kv	
Ratio of estimated to actual, negative	0.98	

The method of estimating used in this example naturally gives the same value for both polarities and actual tests indicate that there is little difference between the positive and negative flashover voltages of this combination of wood and insulators.

Example 3. In order to avoid shattering of crossarms when struck by lightning, parallel horn gaps are sometimes used which have shorter spacings than the sections of wood being protected. The intention is to have the flashover voltage of the horn gap somewhat lower than that of the wood in parallel with it, so that flashover will occur over the gap and not along or in the wood.

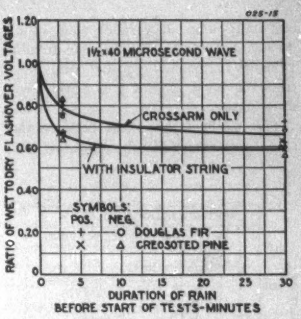


Figure 15. Effect of standard AIEE rain duration on critical impulse flashover voltage of suspension-insulator string and wood crossarm

Using the rod gap curves of figure 3 and the crossarm curves of figure 4, it is possible to estimate horn-gap spacings which will protect wood. Table I illustrates how such an estimate is made.

To protect the crossarm, it is evident that a 25-inch gap would be the longest permissible. In a series of tests run on six-foot sections of four creosoted pine crossarms, the protective gaps were found to be 24, 24, 25, and 27 inches, which are in good agreement with the above estimates.

Example 4. Horn gaps are occasionally used on poles in series with the down-lead to increase the impulse insulation of the pole top with respect to ground. A single pole gap with a 30-inch spacing is oc-

A—Douglas fir, lacquered, test 1
B—Douglas fir, lacquered, test 2
C—Red elm, untreated, test 1
D—Red elm, untreated, test 2
E—Red oak, untreated, test 1
F—Red oak, untreated, test 2
G—Douglas fir, untreated, test 1

Test 1—Four feet of wood plus a four-unit string of 10 by 5¾-inch suspension insulators

Test 2—Four feet of wood plus one 69-kv pin-type insulator

Figure 14. Effects of rain upon impulse flashover voltages of combinations of wood and insulators

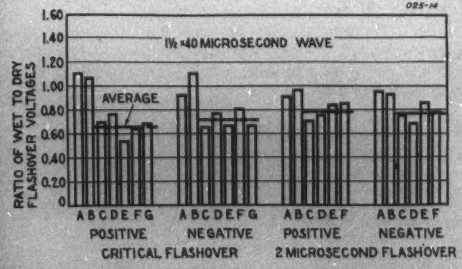
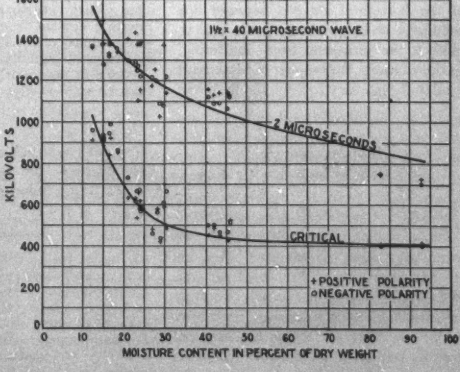


Figure 16. Effects of moisture contents of wood upon impulse flashover voltages of wood crossarms with suspension-insulator strings



casionally used in parallel with about 94 inches of wood. The example in table II shows that such a gap adequately protects the wood, even if it is newly creosoted pine.

The excellent agreement between the actual test values and the flashover volt-

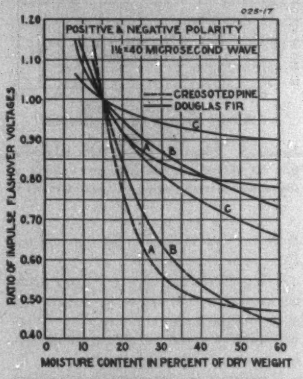


Figure 17. Ratio of impulse flashover voltages for various moisture contents relative to 15 per cent moisture

A—Critical flashovers, crossarms with suspension insulator strings

B—Critical flashovers, crossarms alone

C—Two-microsecond flashovers, crossarms alone or crossarms with suspension insulator strings

age of the equivalent rod gap indicates that rod gap curves may be used for estimating horn-gap flashover voltages with a fair degree of accuracy.

Example 5. In H-frame wood structures it is sometimes desirable to have the flashover voltage of the insulator string and crossarm somewhat greater than that of the horizontal air gap between line conductor and down-lead on the pole to protect the crossarm from shattering. In this example, the number of suspension insulators necessary to force the flashover to occur on the horizontal gap is determined (table III).

Table II. Thirty-Inch Protective Pole Gaps on 94 Inches of Newly Creosoted Green-Pine Poles

	Positive		Negative	
	Critical	Two-Microsecond	Critical	Two-Microsecond
Flashover of 94 inches of pole (figure 5) in kv	700	1,200	700	1,200
Flashover of 30-inch rod gap (figure 3) in kv	500	770	570	770
Actual test value in kv	485		570	

Table III. Required Number of Suspension Insulators on Six Feet of Creosoted Pine Crossarm to Force Flashover on Six-Foot Air Gap to Down-Lead

	Positive		Negative	
	Critical	Two-Microsecond	Critical	Two-Microsecond
Flashover of six-foot rod gap (figure 3) in kv	1,120	1,850	1,270	1,850
Flashover of crossarm with the following number of suspension insulators (figures 2 and 7) in kv:				
6 insulators	1,130	1,510	1,300	1,720
7 insulators	1,190	1,630	1,350	1,840
8 insulators	1,230	1,750	1,410	1,960
9 insulators	1,280	1,870	1,460	2,080
10 insulators	1,340	1,990	1,520	2,200

From table III, it is evident that the nine-unit insulator string is the shortest causing flashover voltages higher than all corresponding voltages of the rod gap. Accordingly, it should be expected to give the desired crossarm protection. In a series of actual tests on creosoted pine crossarms, a ten-unit string was required to cause flashover along the desired path.

Conclusions

1. Properly selected and controlled wood may add appreciably to the lightning insulation of a line. The magnitude is more or less in proportion to the wood length and may be estimated from curves presented in this paper.

2. Almost without exception, the lower the moisture content of wood the higher will be its supplementary lightning insulation value; in particular, reducing the moisture content from an average green-wood value of about 35 per cent to an average moisture equilibrium value of about 15 per cent may nearly double the insulation strength of creosoted pine structures, and raise that of fir structures by about one-fourth. The increase for various moisture contents may be estimated from figure 17.

3. During a rain storm, the lightning insulation strength of structures utilizing wood as supplementary insulation may suffer reductions to as low as 65 per cent of the dry flashover voltage within two or three minutes after the start of rainfall; further reduction, with continuation of the rain, is inappreciable.

4. The supplementary lightning insulation strength of wood is not appreciably altered by the grade of creosote, degree of retention, or creosoting process used in its treatment.

Reference

1. Lightning Strength of Wood in Power Transmission Structures, Philip Sporn and J. T. Lusignan, Jr. AIEE Transactions, volume 57, 1938, pages 91–101.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

Analysis of Bushing-Current-Transformer Performance

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Synopsis: This paper is a presentation and discussion of the more important results obtained in a series of extensive tests made on bushing current transformers. In addition to the determination of the ratio and phase-angle characteristics, tests were made to determine the division of current in interconnected secondary circuits for conditions simulating actual faults in the primary circuit. It is also shown that most of the results obtained from the tests may be readily calculated from the excitation-current data.

IN the application of protective relays for transmission and high-voltage distribution substations, it is vitally important to give careful consideration to the ratio and phase-angle characteristics of the bushing current transformers used as accessory equipment. This has long been recognized, but the necessity for a wider scope of understanding of these factors and more information as to the methods of taking them into account has increased during recent years on account of the performance requirements of modern relaying schemes designed to provide more effective assurance of uninterrupted service. Furthermore, where there are multiple interconnected secondary circuits with totalizing phase and residual burdens such as result, for example, in a bus differential scheme of protection, there is the additional problem of determining the current distribution in the various branches of the secondary circuit for both balanced and unbalanced fault conditions.

The manner in which the ratio and phase relations of the secondary current to the primary current are affected by the components of current required for the excitation of the core and to supply the losses for steady-state conditions is well known,[1] but it is necessary for design and operating engineers to have more complete data than heretofore available, and to be provided with suitable methods of calculating the over-all performance under various conditions which may exist in the field. Similar information is also required regarding the performance during transient conditions but this phase of the problem is beyond the scope of this paper.

In order to obtain the necessary data regarding the performance of a particular relaying scheme, a series of extensive laboratory tests was made on a specific type of multiratio bushing current transformer for various secondary conditions. The purpose of this paper is, first, to present the more important results of these tests, and second, to show that the results so obtained can be calculated with reasonable accuracy from the in-phase and quadrature components of the excitation curves.

Some information regarding the wave-shape distortion of the secondary current by reason of the excitation component was also obtained and data regarding this phase of the tests are given in this paper.

Description of Transformers and Classification of Tests

The current transformers upon which the tests were conducted are quite similar in design to those in general use, consisting of a circular laminated core of silicon steel, a secondary winding with taps for different turn ratios, and a single-turn primary formed by the stud of the oil circuit breaker passing through the center of the core. By proper selection of the taps, turn ratios from 10 to 1 up to 120 to 1, with the exception of 70 to 1 and 110 to 1, may be obtained. In order to obtain better operating characteristics, these transformers were designed specifically to have larger core volumes than had previously been used.

For the purpose of this paper, the tests that were made may be classified and briefly outlined as follows:

(*a*). Ratio and phase-angle tests for different turn ratios and burdens.

(*b*). Single-circuit tests to determine the magnitude and phase relation of the current in each portion of the interconnected secondary circuits, and under conditions equivalent to a line-to-ground fault. The tests were made for three different turn ratios and for several different burdens.

(*c*). Double-circuit tests, similar to the preceding single-circuit tests.

(*d*). Miscellaneous tests, such as excitation curves of the transformers, the taking of oscillograms during the tests, and the determination of the burden characteristics.

Test Equipment and Procedure

Inasmuch as a high degree of accuracy such as is required for billing metering was not deemed necessary for the intended purposes, practically all of the tests were carried out with portable voltmeters, ammeters, wattmeters, and previously standardized instrument transformers.

The primary bus currents were obtained from low-voltage loading transformers, the primary voltage of which was controlled by a 25-kva single-phase induction regulator. Although this voltage regulator was overloaded during some of the tests, involving the higher burdens, and caused some distortion of the primary voltage and current waves, there is good reason to consider, as will be shown later by the closeness of calculated values with actual test values, that the results of the tests were not affected seriously by reason of the distortion that was introduced in the primary currents of the transformers. It is believed that the very presence of distortion for the higher current values actually aided in arriving at some important conclusion as to the amount of distortion introduced in the secondary current by reason of the large third harmonic component required by the excitation component of the primary current.

All of the oscillograms shown in the accompanying figures were obtained from a cathode-ray oscillograph, having a photographic attachment. A number of check oscillograms, however, were taken with a magnetic-type of oscillograph and it was found that there was a substantially close agreement of the waves obtained with the two different types of oscillographs.

Burdens

Three different types of burdens were used during the tests: (1) variable nonsaturating burdens capable of carrying secondary currents up to 80 amperes; (2) nonsaturating burdens of lesser carrying capacity for the portions of the interconnected secondary circuits in which the secondary current did not exceed 10 amperes; and (3) saturating burdens made up of relay coils, compensator coils, and other iron-core reactive devices. It was the intention at first to use actual relays for the saturating burdens, but it was found that the windings could not stand the heavy secondary currents for the period of time

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J. A. GEBELEIN is with the Consumers Power Company, Jackson, Mich., and J. A. ELZI is with the Commonwealth and Southern Corporation, Jackson.

1. For all numbered references, see list at end of paper.

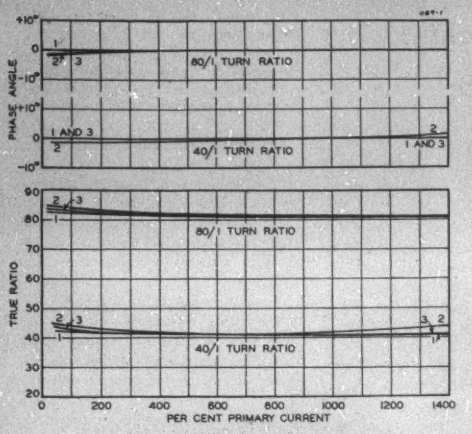


Figure 1. Phase-angle and ratio characteristics

Nonsaturating burdens, 40/1 and 80/1 turn ratios

Curve 1—18 volt-amperes, 0.5 power factor, single transformer

Curve 2—50 volt-amperes, 0.5 power factor, single transformer

Curve 3—50 volt-amperes, 0.5 power factor, two transformers in series

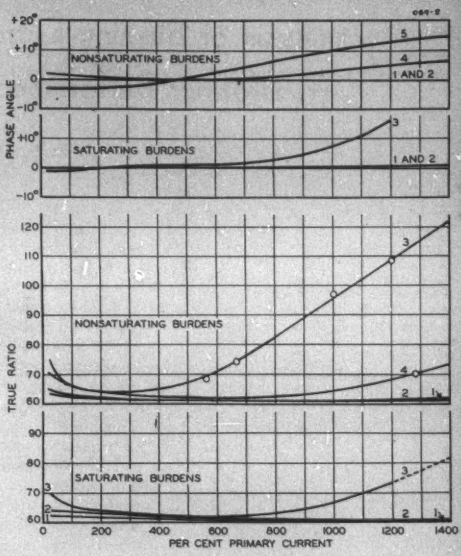


Figure 2. Phase-angle and ratio characteristics

Saturating and nonsaturating burdens, 60/1 ratio

Curve 1—18 volt-amperes, 0.5 power factor

Curve 2—50 volt-amperes, 0.5 power factor

Curve 3—200 volt-amperes, 0.5 power factor

Curve 4—100 volt-amperes, 0.5 power factor

required to take the various instrument readings.

Single-Phase Ratio and Phase-Angle Characteristics

Figures 1 and 2 show the ratio and phase-angle characteristics for three different turn ratios—namely 40:1, 60:1, and 80:1. There does not appear to be much necessity to enter into any detailed analysis of these curves, excepting to call attention to the fact that while in this type of current transformer there is a greater deviation from true ratio and phase angle at values of current near rated current than is permissible in instrument transformers, the reverse is true for the higher values of current. Relay performance is usually associated with current magnitudes well above the rated current of the transformer, and from this standpoint the bushing current transformer is superior to an instrument type. There are, however, cases where relays are required to operate at values of current approaching full-load current, so that the entire performance curve is of importance. The curves also bring out the fact that, particularly for relatively heavy burdens at poor power factor, the ratio and phase-angle characteristics are much better for the higher turn ratios than they are for the lower ones, and a real advantage can frequently be gained by using the higher turn ratios.

In order to show to what extent the ratio and phase-angle performance has been improved by using the extra-volume cores, it would undoubtedly be interesting to present at this point some corresponding curves for transformers having smaller volumes. Unfortunately, such data are not readily available but an equation has been derived from the test data which expresses the approximate relation between a change in volume from a reference volume and the ratio of the primary current to the secondary current. This equation, together with its derivation, is given in the appendix.

A number of tests were made on two transformers with their secondaries connected in series, curves of which are given in figure 1 and show that for burdens of less than 50 volt-amperes and with turn ratios above 40:1, there is little gain in actual accuracy, at least for the primary currents that have been considered. From the test results, and also from the equation that has been deduced for the volume-ratio relation, it appears that the ratio curves that will be obtained for two transformers with their secondaries in series for a certain burden, are approximately the same as is obtained with one transformer with half that burden.

The curves so far discussed apply to nonsaturating burdens. In figure 2, curve 3, the ratio and phase-angle curves are shown for a 200-volt-ampere saturating burden, on the basis of a five-ampere rating. During the tests, a complete record was kept of the volt-ampere burden that the saturating burdens imposed upon the secondary and it was found that a nominally rated 200-volt-ampere saturating burden actually imposed the equivalent of a 110-volt-ampere nonsaturating burden at 55 amperes secondary current. This change in the relative value of the burden will explain why the curve for a 200-volt-ampere saturating burden corresponds very closely to the curve for the 100-volt-ampere nonsaturating burden. Inasmuch as the burdens obtained in actual installations have in general saturating characteristics of widely varying degree, it may be important in some cases that these saturating characteristics be known and taken into consideration.

It is, of course, to be understood as previously stated that the test results apply only for steady-state conditions. Some information regarding the performance of current transformers under transient conditions, particularly for primary currents within the rating of the transformers, has been published.[1-3] In conducting the

tests described herein, due precautions were taken to eliminate any residual magnetization of the cores which might affect the results of the tests.

Calculation of Ratio and Phase-Angle Characteristics

It is generally accepted that in the case of standard types of instrument transformers operating below the saturation point, the ratio and phase-angle characteristics can be calculated from the excitation characteristics and give results that are in substantial agreement with actual test data.

The symmetrical form of the core of the bushing transformers and the practically uniform distribution of the secondary winding, at least for the higher turn ratios, gave reason to consider that it should be possible similarly to calculate their ratio and phase-angle characteristics. This is very desirable because of the expense and equipment necessary to make actual tests, especially at the higher current values.

Figure 3 shows the in-phase and quadrature components of the excitation current as obtained in the test made on the secondary side with 40:1, 60:1, and 80:1 turn ratios. In these excitation tests, the current values were measured by dynamometer ammeters. The voltages for the lower values were measured with a combination of a high-resistance rectifier voltmeter and ratio box. This combination was checked for each reading against a dynamometer voltmeter and care was taken to insure that the check test was made under practically the same voltage wave form as in the actual test. The relative proportion of in-phase and quadrature components of the excitation current was obtained by calculation from the watt loss measurements and the volt-ampere values. The power measurements were made with wattmeters having high-resistance voltage circuits and the readings were duly corrected for the losses in the test instruments themselves, the amount of which was very considerable at the lower values of excitation current.

The procedure for calculating the ratio and phase-angle characteristics from the excitation data is well known and fairly simple. Starting with a definite value of secondary current, the voltage necessary for a specific secondary burden is calculated. For accurate results the leakage reactance of the secondary winding itself should be taken into consideration in calculating the required secondary voltage. For the transformers under consideration the combined effect of the secondary resistance and leakage reactance was approximately 0.1 ohm and is practically constant for the three turn ratios of 40:1, 60:1, and 80:1. Knowing the voltage required, the corresponding excitation components are obtained from the excitation curve and added vectorially to the secondary current and the resultant multiplied by the turn ratio to obtain the corresponding primary current. Five or six such calculations for different secondary currents are generally sufficient to obtain the ratio curve. The encircled points shown in figure 2 indicate the calculated values as obtained by this procedure. If the calculations are made by the rectangular-component method, with the induced voltage taken as the reference axis, the phase angle between the secondary current and the primary current reversed can be determined.

Inasmuch as bushing current transformers are in general provided with a number of taps on the secondary winding, in order to obtain various turn ratios, it was considered desirable to determine whether the excitation curve for a certain turn ratio would be applicable for other turn ratios. For conditions below saturation, the excitation current may be considered approximately inversely proportional to the square of the turn ratio, but for conditions in the saturation region, this relation does not hold true, and hence in using the excitation curve of a particular turn ratio for calculating the values for some other turn ratio, it is found necessary to modify the procedure for calculating the excitation components.

Designating as N_1, the turn ratio for which the excitation curves are available and as N_2 the turn ratio for which the corresponding curves are desired, the first step is to obtain the excitation values for voltage values equal to $E \times N_1/N_2$ and the second step to multiply the values so ob-

Figure 3. Excitation curves

Points for 40/1 ratio calculated from 60/1-ratio curve

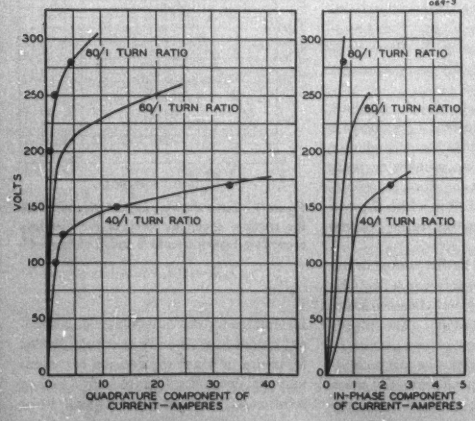
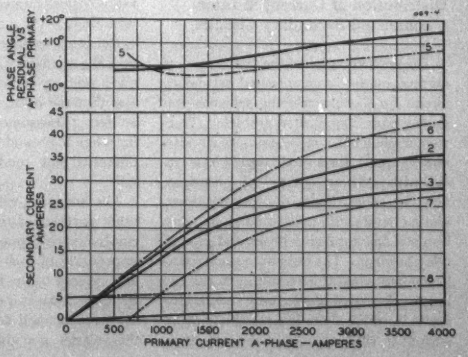


Figure 4. Current division for circuit shown in figure 6a

Nonsaturating burdens, 200 volt-amperes, 0.5 power factor residual circuit, 18 volt-amperes, 0.5 power factor each phase circuit

Zero current in primaries *B* and *C*:
Curve 1—Phase angle
Curve 2—*A*-phase secondary
Curve 3—Residual
Curve 4—Average *B* and *C* secondary

300 amperes in primaries *B* and *C*:
Curve 5—Phase angle
Curve 6—*A*-phase secondary
Curve 7—Residual
Curve 8—Average *B* and *C* secondary



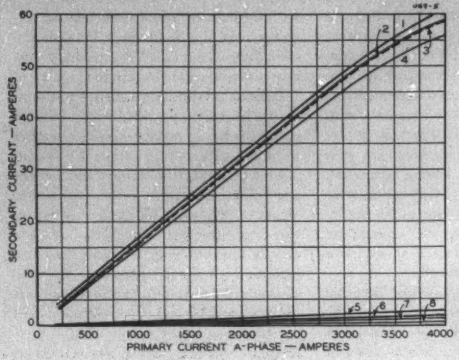


Figure 5 (left). Current division for circuit shown in figure 6c

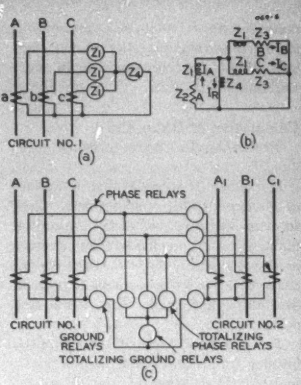


Figure 6 right). Typical circuits involving interconnected secondary circuits

Nonsaturating burdens; 50 volt-amperes, 0.5 power factor totalizing residual circuit; 18 volt-amperes, 0.5 power factor each phase circuit; 18 volt-amperes, 0.5 power factor each phase totalizing circuit; zero volt-amperes each circuit residual

Zero current in all primaries except phase *A*

Curve 1—*A*-phase circuit number 1 secondary

Curve 2—*A*-phase totalizing

Curve 3—Residual circuit number 1

Curve 4—Totalizing residual

Curve 5—Residual circuit number 2

Curve 6—*B* or *C* phase totalizing secondary

Curve 7—*A*-phase circuit number 2 secondary

Curve 8—Average *B* and *C* secondary circuits 1 and 2

tained by N_1/N_2. The result gives the excitation components for the N_2 turn ratio at E volts. The encircled points in figure 3 show the calculated values of the excitation components for the 40:1 and 80:1 turn ratios obtained from the 60:1 excitation test curves by the above procedure.

Distribution of Current in Interconnected Secondary Circuits

The determination of the distribution of current in the interconnected secondary circuit for various relaying schemes presents a more complicated problem. Tests were made for two representative circuits, one, figure 6*a*, for a single three-phase circuit with phase and ground relay burdens, and the other, figure 6*c*, for two three-phase circuits with individual phase relay burdens and totalizing phase and ground relay burdens. The tests were made simulating fault conditions resulting in current in one primary conductor only and also for faults in which there is a relatively small current in the two unfaulted conductors. The results of these tests are shown by the curves of figures 4 and 5.

In addition to providing information as to the distribution of current for the particular current transformers and burdens tested, a study of the results has been of assistance in arriving at analytical methods of calculating the distribution of current in similar circuits from the excitation characteristics of the current transformers and the impedance of the various burdens. It may be safely assumed that whatever current will flow through the idle secondaries will be in the nature of an excitation current and that no appreciable power or apparent power will be transformed to the respective primary windings of the two transformers. In other words, the impedance offered by each of these idle secondary windings is the same as the excitation impedance. In the case of primary currents in each of the three phases, a solution is obtainable by making calculations for each primary current separately, assuming no current in the other two primary conductors. The final result may then be obtained by superimposing the three separate solutions numerically or, if necessary, vectorially.

Referring to figure 6, let it be assumed that the secondary current I_A is due to a given primary current in the A conductor and that the other two primary currents are zero, the assumed condition representing a line to ground fault in which the two unfaulted line conductors carry no current.

The current I_A will be distributed in the other portions of the interconnected circuit in inverse proportion to the respective impedances of each branch. The impedance offered to the flow of any part of I_A by each of the two otherwise-idle secondary windings will depend primarily upon the voltage available at their respective terminals and their excitation characteristics. If the available voltage at the terminals of the windings can be determined, the value of the corresponding current may be obtained from the secondary excitation current and voltage relation. Therefore, in order to analyze the distribution of current in the interconnected circuit, it is necessary to determine the relative value of this voltage with respect to the current that may flow. Such a relationship may be deduced very readily for the simple circuit shown in figure 6*a*. For a more involved circuit, as for example that shown in figure 6*c*, the solution may be obtained by successive approximations. Although a rigorous solution may undoubtedly be

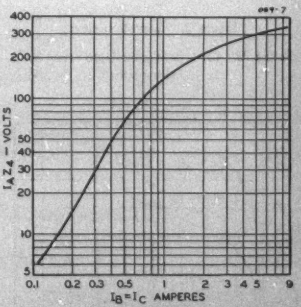


Figure 7. Curve showing current diverted from the residual circuit by each of the two idle secondary branch circuits B and C of figure 6b

$$I_AZ_4=I_B(Z_1+2Z_4)+E_3$$

formulated for any interconnected secondary circuit and a family of curves plotted by means of which the division of current may be determined graphically, such a solution will not usually be found to be

necessary because of the uncertainty of the accurate determination of other factors, as for example, the value of the fault current itself. It is for this reason that it is considered that certain other assumptions are justifiable.

In the treatment which follows, the assumption is made that if the power factor of all the secondary burdens be considered to be approximately 0.5, then the secondary current and the excitation current through the idle secondary windings may be added numerically instead of vectorially and thereby lead to a simplification of the problem and still give results that appear to be sufficiently accurate for the intended purposes. With the assumptions that have been mentioned, the following analysis has been made using figure 6*b*, which is the simplified circuit for figure 6*a*.

LEGEND

Z_t = total impedance imposed on the A secondary winding

I_A = secondary current in the A secondary winding due to primary current in phase A. Primary current in phases B and C equal to zero

E_1 = total voltage induced in the A secondary winding

E_2 = voltage available at terminals of branch circuits

E_3 = voltage available at terminals of idle secondary windings

The other symbols used below are shown in figure 6*b*.

$$Z_t = (Z_1+Z_3)+(Z_1+Z_4)Z_4/D \quad (1)$$

$$D = Z_1+Z_3+2Z_4 \quad (2)$$

$$E_1 = I_A Z_t \quad (3)$$

$$E_3 = E_1 - I_A(Z_1+Z_3) = I_A(Z_1+Z_3)Z_4/D \quad (4)$$

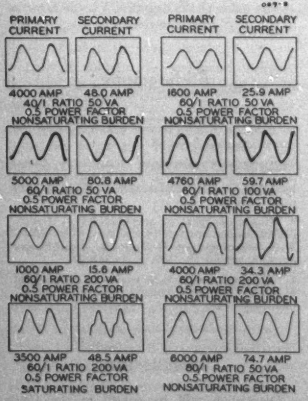
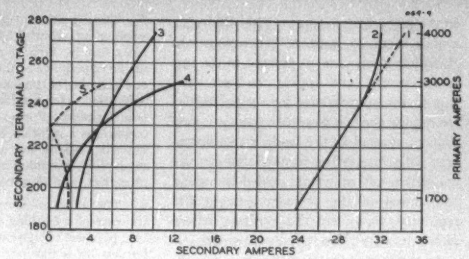


Figure 8. Oscillograms of typical primary and secondary current wave shapes

Figure 9. Relation of fundamental and third harmonic components of secondary current

200-volt-ampere nonsaturating burden, 60/1 turn ratio



$$I_B = I_C = I_A Z_4/D \quad (5)$$

$$I_R = I_A(Z_1+Z_3)/D \quad (6)$$

$$E_3 = E_2 - I_B Z_1 = I_A Z_3 Z_4/D \quad (7)$$

Substituting E_3/I_B for Z_3 in equation 7 and simplifying, gives:

$$I_B(Z_1+2Z_4)+E_3 = I_A Z_4 \quad (8)$$

Since the values I_B and E_3 are related by the excitation curve, new curves may be drawn for $I_B(Z_1+2Z_4)+E_3$ versus I_B and from such a curve the value of I_B corresponding to the value $I_A Z_4$ may be found.

Figure 7 shows such a curve and it is derived from the excitation curve for the 60:1 turn ratio. The burden values Z_1 and Z_4 are taken as 0.8 and 8.0 ohms respectively, the same as were the values of the burdens used in the interconnected secondary circuit in the test for which curves are shown in figure 4. A curve closely approximating curve 4 in figure 4 can be obtained by means of the curve, figure 7.

In the case of the double interconnected circuit shown in figure 6*c*, the best procedure appears to be to start with a first approximation of the current in the residual circuit and proceed to the other branches, using a voltage and current relationship as was done for the simple circuit. In connection with this particular interconnection, attention is called to the possibilities that the amount of current diverted away from the totalizing residual circuit by the A_1 branch circuit may reach values equal to or even greater than the residual current itself if the burdens of the phase relays and circuit ground relays are low compared to the totalizing ground relays.

Wave Distortion of Secondary Current

The excitation component of current introduces not only ratio errors and phase-angle displacement but also affects the secondary-current wave shape. During the tests, numerous oscillograms were taken of the primary current, the secondary current, and the secondary induced voltage.

Curve 1—Secondary current, equivalent sine wave

Curve 2—Secondary current, 60-cycle fundamental

Curve 3—Secondary current, third harmonic

Curve 4—Excitation current, third harmonic on secondary basis

Curve 5—Third harmonic in primary current on secondary basis

Additional oscillograms were also obtained of the excitation current. Most of those which showed considerable distortion were analyzed for the fundamental, the third, the fifth, and the seventh harmonic components. A number of these oscillograms are given in figure 8.

The theory of wave distortion by transformers in general and its effect on relay operation has been discussed in previous publications[1,4] and only a brief discussion of the test results is given here. It will be noted from the oscillograms that the distortion is very small for the low burdens. In the case of a 50-volt-ampere burden and with 60:1 turn ratio, the distortion in the secondary current does not become noticeable until the primary current reaches a value of 5,000 amperes, or 16.7 times the normal primary-current rating. In the case of the 200-volt-ampere burden, distortion begins at about 1,200 amperes, or four times the normal rating.

The curves in figure 9 which show the actual values in amperes of the fundamental and the third-harmonic component in the secondary current for different values of secondary-terminal voltages, were obtained by analyzing the oscillograms made during the tests on the 60:1 turn ratio and a 200-volt-ampere nonsaturating burden. Curve 4 in this figure was plotted from the excitation-current wavesobtained during the excitation-current tests on the 60:1 turn ratio. The dashed curve number 5, shown in this figure, represents the difference between the third harmonic component actually required for excitation (on a secondary basis) and the amount of the third-harmonic component

in the secondary current. This difference would seem to indicate the amount of third-harmonic current present in the primary current, and appears to have been due to the single-phase induction regulator used in the test to regulate the primary voltage applied to the loading transformers. It is interesting to note that for the condition of minimum third-harmonic component in the primary current the regulator was near the position where minimum distortion may be expected.

Analyzing the matter further, it appears tenable to state that the amount of the third-harmonic component in the secondary current is approximately equal to the vector difference of the third harmonic actually present in the primary current and the amount of third-harmonic current actually required for excitation, all values reduced to a secondary basis. Hence, the further deduction that if the fault current during a line-to-ground fault is sinusoidal, then the amount of third-harmonic component present in the secondary current should be equal to the third-harmonic component required for excitation. Although this would be true only if the burdens are nonsaturating, nevertheless, it would appear from the analysis of some of the oscillograms that with saturating burdens, the amount of the third harmonic is not altered very greatly from that with nonsaturating burdens, excepting that there is a different phase displacement of the third-harmonic component with respect to the fundamental which results in a more peaked secondary-current wave for saturating burdens than is the case for nonsaturating burdens.

As to the fifth and higher harmonics, no attempt was made to correlate the results, mainly because the analyzation of the waves for such harmonics could not be carried out within a reasonable degree of accuracy.

Conclusions

Although this series of tests was made on a specific set of bushing current transformers, an analysis of the results leads to certain conclusions which are applicable to this general type of transformer. These may be summarized as follows:

1. Bushing current transformers having cores of adequate volume and reasonably high turn ratios have characteristics which are very desirable from the standpoint of relay application and in some cases may be superior to instrument-type transformers.

2. The performance characteristics of bushing current transformers can be determined with reasonable accuracy from the in-phase and quadrature components of the excitation current.

3. The distribution of current in circuits involving interconnected transformer secondaries can be arrived at by a consideration of the impedance of the burdens in the various branches of the secondary circuit and the excitation characteristics of the current transformers. For various primary circuit conditions a solution is obtainable by making calculations for each primary current separately, assuming no current in the other primaries, and then combining results.

4. The effect of increasing the volume of the core of a bushing transformer by a certain per cent is equivalent to decreasing the burden by a like per cent. Likewise, the use of two bushing transformers in series is equivalent to reducing the burden on one to half the total burden.

Appendix

True Ratio Versus Change in Core Volume

The relation of the true ratio versus change in core volume, is a function of the excitation current required for a particular burden. If the volume is increased by changing the axial dimension and the radial dimensions remain the same, the magnetic cross section will be increased correspondingly and hence for a given number of turns in the secondary winding and for a given excitation current, the flux and the voltage induced by the flux, will be increased in the same proportion. The iron losses will of course enter into consideration but it can be shown that the effect is negligible.

For instrument transformers which generally operate below the knee of the saturation curve, factors other than the true ratio, in general, determine the core dimensions. In the case of bushing current transformers with low ampere-turn ratings, the ratio accuracy is one of the important factors which determine the core dimensions. Inasmuch as this discussion is concerned mainly with reference to conditions in the saturated region, it is of interest to analyze the relationship of the true ratio with respect to changes in the core volume, for such conditions only.

For such an analysis, the portion of the excitation curve above the knee may be represented by an equation of the form $I=k_1E/(1-k_2E)$. Now if V_1 represents a reference volume and V_2 the volume for which the ratio characteristics are desired, then if the change in volume from V_1 to V_2 is a change in the axial dimension only, the respective excitation currents, of the two volumes, will be:

For volume V_1,

$$I_{s1}=k_1E_{s1}/(1-k_2E_{s1}) \tag{9}$$

For volume V_2,

$$I_{s1}=k_1E_{s2}V_1/(V_2-V_1k_2E_{s2}Z) \tag{10}$$

The values E_{s1} and E_{s2} may be replaced by the respective products $I_{s1}Z$ and $I_{s2}Z$ in which I_{s1} and I_{s2} are the respective secondary currents and Z is the impedance of the secondary burden.

For the purpose of this analysis, the secondary burden is considered to have a power factor of 0.5 and on this basis the assumption is made that the excitation-current component and the secondary current are close enough in phase to permit adding their values numerically instead of vectorially. The respective true ratios for the two volumes are then given by equations 11 and 12.

$$R_1=N\left(1+\frac{k_1Z}{1-k_2ZI_{s1}}\right) \tag{11}$$

$$R_2=N\left(1+\frac{k_1ZV_1}{V_2-V_1k_2ZI_{s2}}\right) \tag{12}$$

Substituting $I_{p1}=R_1I_{s1}$ and $I_{p2}=R_2I_{s2}$ in the two preceding equations, and equating the two for $R_1=R_2$, gives the following relationship of the primary currents:

$$I_{p2}=I_{p1}+\frac{(V_2-V_1)}{V_1}\frac{R_1}{K_2Z_1} \tag{13}$$

Hence, if the corresponding values of I_{p1} and R_1 are known for volume V_1, the corresponding primary current I_{p2}, for which the true ratio is equal to R_1, may be calculated. The value of the constant k_2 may be determined from the excitation-current curve.

The conclusion that may be deduced from curves plotted by means of equation 13 may be stated in various ways but it would seem that the following would best serve the purpose, namely, that the gain in ratio accuracy that is obtained by increasing the axial dimension of the core by a certain percentage is approximately the same as would be obtained with the original volume by reducing the value of the burden the same percentage.

Ratio Versus Burden Impedance

For approximate determination of the ratio curve for a burden of Z_1 ohms impedance, if the curve is known for a burden of Z_1 ohms and of the same power factor as Z_2, the following equation has been found to give sufficiently accurate results for conditions in the saturating region.

$$I_{p2}=I_{p1}+\left(\frac{Z_1-Z_2}{Z_1}\right)\frac{R_1}{KZ_1}$$

The value of the constant k is the same as in the preceding equation 13.

Bibliography

1. Relay Systems (a book), I. T. Monseth and P. H. Robinson. McGraw-Hill Book Company, first edition, chapters 9 and 14.

2. Current-Transformer Excitation Under Transit Conditions, D. E. Marshall and P. O. Langguth. AIEE Transactions, volume 48, 1929, pages 1464–74.

3. Considerations in Applying Ratio Differential Relays for Bus Protection, R. M. Smith, W. K Sonnemann, and G. B. Dodds. AIEE Transactions, volume 48, 1939, pages 243–52.

4. Electric Circuits (a book), O. G. C. Dahl. McGraw-Hill Book Company, volume 1, first edition, chapter 8.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

A Proposed Method for the Determination of Current-Transformer Errors

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CURRENT TRANSFORMERS for relay service must be able to function with reasonable accuracy under very high overload conditions, and it is therefore necessary that their accuracy for such high currents be verified. However, in performing the usual accuracy test at very high currents, certain difficulties are encountered—the principal ones being:

(*a*). The difficulty of providing large amounts of power at large current values and bus-bar type wiring required. The kilovolt-amperes required at 20 times normal current is 400 times that at normal current.

(*b*). The necessity for standard burdens capable of withstanding heavy currents.

(*c*). The necessity for taking the meter readings very rapidly—within a few seconds—in order to avoid overheating of the current-transformer windings.

This paper proposes an indirect method for determining the accuracy characteristics—phase angle and ratio—of a current transformer for both normal and abnormal currents, whereby the difficulties of test mentioned above are obviated, with no sacrifice of essential accuracy. It consists in the determination by test of the impedance and of the excitation characteristics of the transformer and calculating from them the ratio and phase-angle errors of the transformer.

In this respect the proposed indirect method, as a method of calculation of the *current* regulation of the transformer, falls in identically the same category as the standard procedure for determining the voltage regulation of a power transformer indirectly from impedance measurements.

Equivalent Circuit of a Transformer as Reduced to 1:1 Ratio

The errors of a current transformer arise from the fact that not all of the primary current is transformed, a component (I_e) being used to excite the core. This may be seen more clearly by referring to the conventional equivalent circuit of a transformer as shown in figure 1. In this diagram R and X are respectively the resistance and the reactance of the external burden, and r_1, r_2, x_1, x_2, respectively the resistances and reactances of the primary and secondary windings.

The exciting current is conceived of as occasioned by a load in a fictitious third winding. From the equivalent circuit it is easily seen that the value of the by-passed exciting I_e depends upon the value of the induced voltage E_2, and it follows therefore that the characteristics of a current transformer are defined when the values of r_1, r_2, x_1, and x_2 are known and the exciting current I_e is given as a function of E_2.

For if these values are known, then it follows from the equivalent circuit that:

$$I_2 = I_1 - I_e \qquad (1)$$

and:

$$E_2 = I_2\{(r_2+R)+j(x_2+X)\} \qquad (2)$$

and consequently the ratio $|I_2|/|I_1|$ and the phase angle $(\angle I_2 - \angle I_1)$ can be determined as illustrated below.

Determination of the Leakage Reactances

Of course r_1 and r_2 can be measured directly across each winding. In order to be able to measure the primary and secondary leakage reactance voltages directly it is necessary that there be only load currents in the windings and no exciting current—that is, the primary and secondary ampere turns must be exactly equal and opposite. This condition can be realized in a 1:1 ratio transformer by connecting the primary and the secondary windings in series opposition and forcing the desired current through them.[1] The voltages measured across each winding are then caused respectively by the "primary" and "secondary" internal impedances of the transformer. Knowing the current, the leakage reactances x_1 and x_2 can be calculated.

To insure equality of primary and secondary ampere turns in transformers other than 1:1 ratio, some expedient must be introduced. One such method is illustrated in figure 2. This figure shows a bushing-type current transformer. However, the scheme can be used for any current transformers provided they do not incorporate methods of compensation other than the regular turn compensation. In figure 2, B is the transformer of which it is desired to determine the secondary leakage reactance; A is an auxiliary current transformer which is used to balance the primary and the secondary ampere turns of the transformer B.

The auxiliary "balancing" current transformer A is wound with suitable taps and its ratio of transformation is chosen

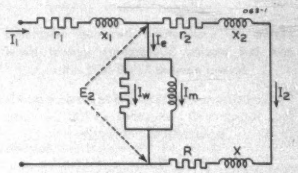

Figure 1. Equivalent circuit of a current transformer

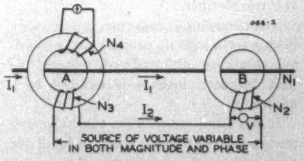

Figure 2. Method for determining the secondary impedance of a current transformer

to be *identical* with that of current transformer B under test. The auxiliary current transformer A has also an exploring winding $N4$ which is connected to a vibration galvanometer.

The primary winding of the transformer to be tested is connected in series with the primary winding of the balancing transformer and to a source of voltage supplying the primary current. Likewise the secondary windings of the transformers are connected in series and to a source of voltage supplied by a phase shifter.

The phase and magnitude of the current supplied by the phase shifter are ad-

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1. For all numbered references, see list at end of paper.

justed until the flux in the balancing transformer is zero. This is determined by a zero reading on the vibration galvanometer. The value of I_2 is measured by an ammeter and the voltage V by a voltmeter, across the secondary of the

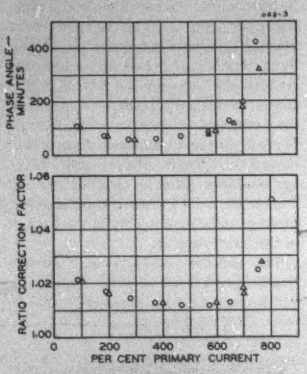

Figure 3. Comparison between calculated and test results, 300-ampere current transformer number 1, 60-to-1 ratio

Bushing type with distributed secondary winding; burden 50 volt-amperes, 100 per cent power factor, 60 cycles

⊙—Calculated △—Test

transformer B. The latter is proportional to the internal secondary impedance of the transformer.

The balancing transformer is preferably of ring form with its primary and secondary windings uniformly distributed so that magnetic leakage is reduced to a minimum.

It has been stated that the balancing transformer of figure 2 needs to be of the same ratio as the current transformer under test. To fulfill this requirement it is necessary to know the secondary number of turns of the current transformer. There are several ways in which this can be obtained by test,[2] but the description of these methods falls outside the scope of this paper. Of course the simplest way is to obtain this information directly from the manufacturer.

In these tests, two methods were used for obtaining the variable source of voltage:

(*a*). By deriving this voltage from a conventional phase shifter (a wound-rotor polyphase induction motor will serve)

(*b*). By the use of two generators the shafts of which are connected mechanically. The stator of one of the generators can be turned with respect to the other

The voltmeter V needs to be of very high resistance. A good plan is to use a copper-oxide voltmeter having an internal resistance of about 1,000 ohms per volt. The Tinsley-Gall a-c potentiometer can also be used to read the above voltage.

Variations of Secondary Reactance With Secondary Current of the Current Transformer

Theoretically the division of the leakage reactance of a transformer varies with the secondary current. The reason for this is that changes in permeability of the core at various densities affect differently the reluctances of the external and internal parts of the magnetic circuit—neither the iron magnetic circuit nor the air mag-

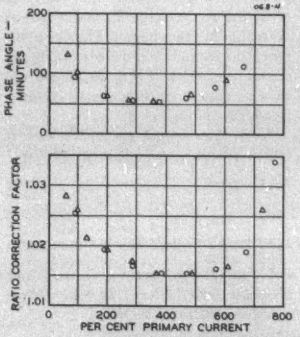

Figure 4. Comparison between calculated and test results, 300-ampere current transformer number 2, 60-to-1 ratio

Bushing type with secondary winding concentrated on approximately one-fourth of the circumference of the core; burden 50 volt-amperes, 100 per cent power factor, 60 cycles

⊙—Calculated △—Test

netic circuit, which are in parallel, having uniform section or length. It is found, however, by actual test that these changes are quite limited and not large enough to affect considerably the accuracy which can be obtained by the proposed method of test. Actual test results of the secondary reactance at two or more values of the secondary current are tabulated under the item of "Test Results".

Determination of Magnetic Properties of Core Material

In order to determine the performance of a given transformer under definite conditions of load, it is now necessary to obtain values of the watt and wattless components of the exciting current (I_e) corresponding to the voltage E_2 which is applied across the secondary terminals of the transformer. It should be noted from the equivalent circuit of figure 1 that theoretically to obtain the actual value of I_e corresponding to the induced voltage E_2 there should be applied across the terminals of the transformer a somewhat higher voltage; but in general the voltage drop caused by the current I_e flowing through the internal impedance of the transformer is very small and can be neglected.

In the measurements of watts and exciting current, the fundamental components of these quantities must be taken. In the tests made for the preparation of this paper, a Tinsley-Gall a-c co-ordinate potentiometer was used.[3] Other methods can be used when this equipment is not available. For instance, the fundamental component of the exciting current can be obtained by means of a separately excited wattmeter, the separate excitation furnished by a phase shifter.

Calculation of Current-Transformer Characteristics From Test Results

If the magnetic properties of the core of the current transformer and the leakage

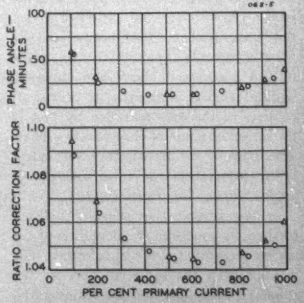

Figure 5. Comparison between calculated and test results, 200-ampere current transformer number 3, 40-to-1 ratio

Bushing type with secondary winding concentrated on approximately one-sixth of the circumference of the core; burden 50 volt-amperes, 100 per cent power factor, 60 cycles

⊙—Calculated △—Test

reactance of the secondary winding are known, the ratio and phase angle for any secondary current or burden on the current transformer can be calculated quite accurately.

Agnew[4] gives the following simplified formulas for calculating the errors in current transformers:

$$\text{ratio } (R) = \left(n + \frac{M \sin \phi + F \cos \phi}{I_2}\right) \frac{1}{\cos \theta} \quad (3)$$

$$\tan \theta = \frac{M \cos \phi - F \sin \phi}{nI_2} \quad (4)$$

where:

I_2 is the secondary current
n is the ratio of number of secondary to primary turns
θ is the phase angle of the current transformer
ϕ is the phase angle of the secondary current with respect to the induced voltage
M is the magnetizing component of the core exciting current
F is the corresponding loss component of exciting current (due to hysteresis and eddy losses in the core)

In order to obtain M and F it is simply necessary to multiply the wattless volt-amperes (VA) and the watts (W) respectively by:

$$\frac{n}{E_2}$$

After obtaining the internal secondary impedance of the given transformer and its excitation characteristics by the use of formulas 3 and 4 it is relatively a simple matter to determine the ratio and phase angle under any conditions of current and of burden. The method will be illustrated by an example and the results compared with test results obtained by a conventional method of testing.

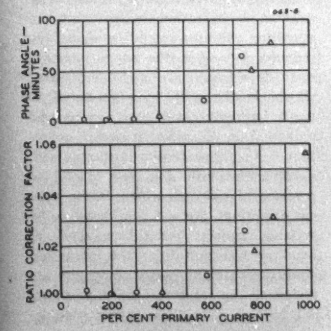

Figure 6. Comparison between calculated and test results, 100-ampere current transformer number 4, 20-to-1 ratio for 4,500-volt circuit

Wound-type current transformer; burden 50 volt-amperes, 50 per cent power factor, 60 cycles

⊙—Calculated △—Test

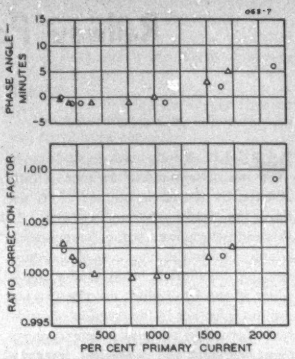

Figure 7. Comparison between calculated and test results, 50-ampere current transformer number 5, 10-to-1 ratio for 69,000-volt circuit

Wound-type current transformer; burden 50 volt-amperes, 50 per cent power factor, 60 cycles

⊙—Calculated △—Test

Sample Calculation

To illustrate the method of test and the necessary calculations to determine the current-transformer errors, the following example is given:

Characteristics required on a bushing-type current transformer rated 300/5 amperes, having a concentrated secondary winding. Core dimensions—inside diameter = 8 inches, outside diameter = 10 inches, height = 3 inches
Secondary turns = 60
External burden = 50 volt-amperes at 100 per cent power factor

Balancing transformer consisting of a bushing current transformer having a core of the following dimensions: inside diameter = 16 inches, outside diameter = 20 inches, height = 3 inches. Secondary turns = 60 uniformly distributed over the core. Exploring winding of 100 turns—also uniformly distributed.

(a). Determination of Secondary Reactance

Test made at five amperes, 60 cycles
Voltage read across the secondary of the current transformer under test (at balance) = 1.70 volts
Measured secondary resistance of the transformer = 0.14 ohm
Calculated secondary reactance of the transformer = 0.31 ohm

(b). Test on the Magnetic Characteristics of the Core

For the sake of brevity only a few points are given:

E	W	I_e	F	M
60.12	20.64	0.775	20.58	41.70
70.32	29.62	1.31	25.50	74.4

(c). Calculation of the Characteristics of the Current Transformer

External burden—50 volt-amperes at 100 per cent power factor
$R = 2 \quad X = 0$
Internal burden—$r_2 = 0.14$, $x_2 = 0.31$
Total secondary impedance:

$R + r_2 = 2.143$
$X + x_2 = 0.31$
$Z = 2.16$

$$\cos \phi = \frac{2.14}{2.16} = 0.99$$

$$\sin \phi = \frac{0.31}{2.16} = 0.143$$

E	I_2	$M \sin \phi$	$M \cos \phi$	$F \cos \phi$	$F \sin \phi$	R	θ
60.12	27.8	5.98	41.3	20.4	2.94	60.96	78′
70.32	32.56	10.68	70.36	25.26	3.66	61.14	2°, 1′

Table I. Measured Secondary Impedances

Transformer Number	r_2	X_2	At I_2 (Amp.)	Remarks
1	0.132	0.002	5	
2	0.143	0.31	5	
3	0.083	0.274	2.3	
3	0.085	0.276	4.55	
3	0.084	0.274	7.83	
4	0.29	0.249	2	
5	0.52	3.65	2.68	Transformer compensated (Wilson method)
		3.48	4.79	
		3.30	7.3	
		3.19	8.7	
5	0.52	2.79	2.67	Transformer uncompensated
		2.79	5.25	
		2.76	9.40	

These results are compared with conventional test in figure 4.

Test Results and Discussion

The following transformers were tested:

1. Figure 3—bushing-type current transformer, wound core, secondary winding uniformly distributed. Ratio 300/5. Inside diameter of core = 8 inches

2. Figure 4—bushing-type current transformer, wound core, concentrated secondary winding—otherwise same as above

3. Figure 5—bushing-type current transformer, wound core, concentrated secondary winding. Inside diameter of core = 18 inches. Ratio 200/5

4. Figure 6—wound-type current transformer for 4,500-volt circuit. Ratio 100/5

5. Figure 7—wound-type current transformer for 69,000-volt circuit. Ratio 50/5. This transformer can be compensated according to the Wilson method. Tests were made with and without compensation

From table I it is noted that the secondary reactance of an annular core with distributed secondary winding is negligible, which confirms the findings of other investigators.[4] Table I and figures 3 to 7 also show that from a practical standpoint the secondary reactance is constant and a measured value at normal current can be used for overcurrent calculations, provided the transformer does not incorporate any compensating scheme other than simple turn compensation. With certain compensating schemes an estimation of this reactance can be obtained by testing at several points and extrapolating. This value can be used when errors are small.

The curves in figures 3, 4, 5, 6, and 7 show good agreement between test values and calculated values up to saturation of the core. The results obtained above saturation in either method (test or calculation) are somewhat indefinite. The method used for the testing recognizes only fundamental values of the primary and secondary currents. At these points above saturation, distortion is unavoidable. It is difficult to duplicate this distortion by calculation, and furthermore there is some doubt whether results in this region are of much value since some relays respond to fundamental values, some to effective values, some to peak values, and others to intermediate values. It should be pointed out, however, that overcurrent tests are more often used to compare the performance of two or more different current transformers and for such purposes the proposed method of indirect testing would appear satisfactory.

Conclusion

A method of testing current transformers has been described which eliminates a number of serious difficulties encountered in the usual methods of testing and is applicable with satisfactory accuracy under practically all current and burden conditions.

References

1. Resolution of Transformer Reactances, A. Boyajian. AIEE Transactions, 1925.

2. Alfred Berghahn, *E. T. Z.*, May 7, 1931.

3. Some Applications of the A-C Potentiometer, T. Spooner. Optical Society of America and *Review of Scientific Instruments*, March 1930, page 217.

4. A Study of the Current Transformer With Particular Reference to Core Losses. P. G. Agnew. *Bulletin*, Bureau of Standards, volume 7, 1911, pages 423–74.

5. H. W. Price, C. K. Duff, papers on current transformers, *Bulletin* Number 2, University of Toronto, 1921.

Railway Power Supply

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FELLOW AIEE

WHILE all industries depend on the use of power few are more vitally affected by the circumstances of its use than the transportation industry. In this industry power not only represents a large item in the total cost of operation but, by the varied forms and ways in which it can be applied, exercises an important influence in the creation of conditions favorable to more efficient movement of freight and passengers, improvement in the standards of service and resultant promotion of the business.

The determination of the type of power most advantageous in a specific case presents a multiplicity of problems which require detailed study by persons who possess extensive practical experience. In a general way, however, all engineers recognize the fact that, where electric power must be utilized in small quantities in widely separated locations, it is more economical to install the generating plant at the point of use. As these locations become more numerous and are grouped together, better results can be secured by generating the power centrally and distributing it to the individual users. Similarly, in generating power for the movement of trains, where they are limited in number and size the conventional method of using a steam locomotive or other power unit on each train is followed with satisfactory results. As the trains increase in number and size a point is reached where it becomes far more economical and satisfactory from every standpoint to install the power-generating facilities at a central location and supply the current to motors on the trains through a distribution system.

In any specific case the railroad executive will have to co-ordinate and evaluate all the gains possible from electrification but, in general, past experience has shown that it may be considered as a means of moving trains in dense-traffic territory at no additional cost and in many cases at considerable saving, while at the same time providing the public with faster schedules and more reliable service and the management with increased capacity of plant. The full benefits of a railroad electrification usually are not secured until after it has been in service for a sufficient length of time to enable the management, through education, training, and supervision, to take full advantage of the improved tool with which it is supplied.

As further experience is secured with railroad electrification the first cost and operating expenses should be materially reduced by using the same intensive methods of supervision and development which, in the past, have produced so much improvement in the service and reduction in the cost of steam operation. As these results are obtained, electrification will doubtless extend to portions of railroads which, under present conditions, are not considered to be suitable projects for this method of handling transportation; the intensified study which many power companies are giving to the subject of railway supply will help to make these results possible.

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Philip Torchio is retired vice-president, Consolidated Edison Company of New York, Inc., New York, N. Y.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

Changing Aspects of Power Supply

When electricity first became available for traction, it found a ready field of application in the transportation of passengers in cities and towns and a new industry was soon developed in which it was used exclusively for motive power on account of its remarkable flexibility in handling such traffic. In the case of existing transportation systems, however, the substitution of electricity for steam encountered the serious obstacle that it would require large new investments, involving the addition of wayside structures, equipment and conductors, possible changes in track and facility provisions, and a complete change in locomotive equipment. For this reason the railroads found it more advantageous to continue their long-established policy of improving the economy of steam locomotives, designing different types for specific services and, more recently, of adopting internal-combustion engines for high-speed light passenger trains, for yard switching, etc. Nevertheless, in certain situations other weighty considerations made it desirable or necessary to adopt electric traction. This was the case in the early electrifications of important terminals serving considerable suburban passenger traffic and, later, where heavy freight traffic and steep grades, or the carrying of freight and passenger traffic in competition with other means of transportation, made the change to electric traction profitable.

In the foregoing developments, the role of the utilities in connection with the supply of power for traction, has passed through two different phases:

Many years ago, when electric traction was first introduced for urban rapid transit and, subsequently, for the more important steam-railroad terminals, the electric utilities were not sufficiently developed to supply advantageously throughout their territories, the large quantities of special current required for traction. Consequently the transportation companies, as a rule, installed their own plants and extensive distributing systems.

Later, because of their rapid growth, the utilities had greatly expanded their generating and distributing facilities and found themselves in a position to supply power to the transportation companies more advantageously than the latter could produce it. This change in conditions prompted the consummation of many contracts for the supply of power.

Type and Scope of Contracts

We shall subdivide these contracts into two types:

First—Those covering the supply of power to railways operating their own generating and distributing plants.

Second—Those covering power sales to railways to be electrified without power plants of their own.

A utility, in dealing with these two classes of contracts, is confronted with distinctly different problems. In the first case it has to prove to the prospective customer that its service will be more advantageous than can be obtained from his old plant even if it is improved by an economical modernization. In the second case the utility has to prove that its service will be more advantageous than the customer can obtain from a heavy investment in modern generating and distributing plant to provide the requirements of the road to be electrified.

First Case

Where the railways owned good-sized 25-cycle plants for generating their power requirements, and the utilities had considerable 25-cycle capacity installed for their own use, the parties were able to evolve special workable power arrangements based on interconnecting the railways' plants with the utilities. The less efficient railway plants were then operated for a minimum number of hours as in the case of the utilities' own generating capacity of older vintage, thereby realizing material operating savings which were equitably shared by both parties. In addition, the railways were relieved of the necessity of generating power, which must be a side issue for them since they are basically engaged in providing transportation, rather than in producing and distributing power economically.

These special power arrangements were dictated by the desirability of making full use of the unexpired economic life of the railways' plants without the necessity of large expenditures for their modernization, as is being successfully done on the utility systems, with assured increasing loads, by the installation of topping turbines. The railways are handicapped in carrying out a modernization program because it is generally difficult for them to dispense with a substantial part of their generating facilities during the protracted period required for reconstruction, and, if the construction plans are so worked out that the existing equipment is not disturbed the cost of the new facilities is likely to be excessive. Furthermore, since their rebuilt plants, in some cases, must be operated at the relatively poor traction load factor, they are not in a position to make the best use of the modern equipment and the operating savings may not be sufficient to counterbalance the added fixed charges. The utilities, by contrast, are in a position to modernize plants and to operate them advantageously for base-load generation, using the railway plants for emergency or standby service thereby filling the former role of the modernized plants. The old railway plants then readily fit in as a part of a co-ordinated program.

There is no standard form for such arrangements because the details to be covered vary greatly in each situation. Special provisions of the contracts usually are similar to those for straight power sales contracts hereafter described. The only essential requisite is that the net results must be such that the railways obtain the service at a lower cost than they could secure for themselves by modernizing their plants in order to raise their efficiencies to the standard afforded by the advancement in the art; and that the utilities obtain sufficient revenue to cover all operating expenses and fixed charges, including amortization of any new investment, plus allocated general expenses, taxes, and a fair share of the savings derived from the bulk production of the increased output. These savings will ultimately accrue to the benefit of the general customers in reduced rates.

Second Case

Contracts for the sale of power to traction companies not owning power plants are not essentially different from the usual form of "demand and energy rate" contracts and include such items as:

term of the contract—character of energy—points of delivery—use to be made of the energy—price of "demand" and "energy" charges—price adjustment for changes in cost of fuel, when power is produced by steam—definition of billing demands—service connections—billings and payments—etc.

In addition such important contracts also contain appropriate provisions, including:

dates for beginning specified partial services and full service—clauses to insure diligence in providing regular and uninterrupted service—access to records—testing of measuring instruments—arbitration—reduction of rates if more favorable rates are given other customers under substantially similar conditions.

In the preparation of each contract, the various provisions are carefully drafted to conform to the unique requirements of the case. Certain distinguishing

characteristics of railway contracts, and the considerations on which they are based, are as follows:

(*a*). A relatively long period of time is specified for the term of the contract and its renewals, if any.—These contracts being for large amounts of important service, it is obvious that the parties must have a relatively long period of guaranteed operation of the facilities provided for the service. Contracts are rarely written for less than 10 years and usually cover longer periods of operation up to 20 years with provision for extension of time should the utility make substantial additions to its facilities for the railway's use during the initial period.

(*b*). A guarantee of payment for a minimum amount of service each year is usually included.—The utility must have a guaranteed minimum payment in order to cover the overhead charges and provide, during the term of the contract, for reasonable amortization of the special investment made.

(*c*). Unusual methods of determining the monthly maximum demand for billing are used.—The operation of a railroad is subject to occasional large variations of maximum demand from causes extraneous to the normal operation. These fortuitous conditions should not be allowed to penalize the railroad unduly. Hence the average of the three highest clock-hour maximum demands in each month has been adopted in a number of contracts as the billing demand. Furthermore, in cases of emergency, the large drafts of power following accidents or abnormal and unforeseen increases in traffic for short periods of time are usually furnished by the utilities, if they have the capacity available, without increasing the billing demand.

(*d*). A provision is included which requires that each monthly billing demand shall not be less than a specified percentage of any previous billing demand.—This supplements the requirements of (*a*) and (*b*) and takes into account the special characteristics of the railway's fluctuation in business from year to year. Except for some of the urban lines this fluctuation is very large, and if the railways were to pay for a high percentage of any previous demand when the traffic has shrunk considerably, their income would be diminished when vitally needed. For this reason they prefer that the unit demand charge be figured high enough to compensate the utility fully during the term of the contract, and that the guaranteed percentage of any previous billing demand which determines the yearly payment for "demand charge", be made more proportional to the amount of maximum load taken during each year.

(*e*). The practice as to whether the railway or the utility should furnish and operate the machines required to deliver direct or single-phase current is not uniform.—In the case of railroads electrified during the last few years the tendency has been to have the utility furnish, house, and operate such apparatus and supply energy directly to the trolley or transmission lines. In such cases provisions are made in the contract price for a proper compensation to cover the operating costs, conversion losses, and fixed charges including amortization. Clauses are also included for transferring ownership to the railway in the event of termination of the contract, at a sale price proportionate to the unamortized investment.

(*f*). The utility, in establishing these differences in the terms of various contracts, carefully analyzes the effect of each variation and accordingly provides price differentials which will avoid discrimination among customers. The general clause on reduction of rate if more favorable rates are given other customers also protects each purchaser in respect to these special provisions.

Underlying Economic Factors

The utilities are justified in making the foregoing departures from their standard forms of power contracts in the case of electrified railways, since experience has shown that this valuable business could not be secured without giving the underlying economic factors full consideration from the standpoints of both the railways and the utilities. We have already made occasional references to these factors but it is also important to explain more comprehensively how they affect the two industries.

Load Factor

In general the utilities have a much higher use of their maximum demand than the railways which means that they are able to render more service per kilowatt of plant capacity. This is caused by the great variety of their customers and the resulting time diversity of maximum demand and use of the service. Furthermore, although the railway's load factor is, in general, less favorable than the utility's, when the two loads are superimposed with their diversity in time of respective maximum demand, the combined load factor is improved and conditions are created for realizing substantial economies in plant investment. These investment economies are, of course, further enhanced by a saving in the amount of spare capacity which would be required if the railway were to install and operate an independent generating system for the lines to be electrified. Similar economies may also be realized in connection with the power transmission system. Therefore, if the railway electrification loads are supplied by a heavily-interconnected utility industry these factors will produce economic results to the advantage of both the railways and the utilities.

Rate of Growth

The utilities with their continuous growth in load, in contrast with the more or less stationary load of a railroad for a given situation, are in a better position to continue to improve their operating economies, as they have done in the past.

These economies were realized in part from the fact that the quantities of power handled by the electric utilities became so large that it was possible for them to install generating and transmission units of large capacity with correspondingly lowered unit costs, reduced operating labor costs, and improved efficiencies. At the same time, the utilities were enabled to produce the major portion of their power requirements from their newer and more efficient units, by operating them at high load factors and gradually relegating their older plant to usage for peak or standby service.

For illustration, the graph, figure 1, gives the distribution of capacity and output according to the date of installation of units for a large system during the year 1934. It shows that of the total capacity, the 20 per cent installed before 1919 was used to give less than 2 per cent of the total output and the 50 per cent installed before 1926 was used to give less than 28 per cent of the total output while the other 50 per cent installed between 1926 and 1934 and incorporating the latest advancements in the art as to the size and efficiency of machines, higher steam pressure, higher steam temperature, more efficient boilers,

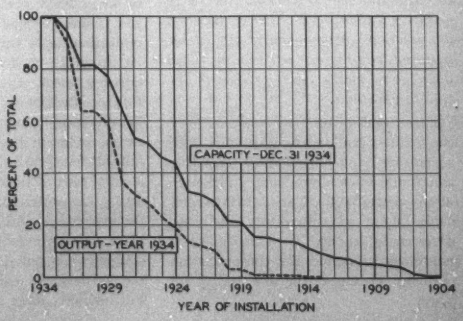

Figure 1. Total generating capacity installed in or prior to indicated year compared with energy generated by corresponding units during the year 1934

and all other station improvements generated 72 per cent of the total output. This progress in securing higher economies is a continuous one as long as the industry is growing.

Sources of Power

In contrast with the foregoing favorable situation of the utilities in supplying power, it is evident that large-scale electrifications under present-day conditions, if served with power by the railways themselves would either require several suitably located and relatively small power plants, which necessarily would involve high unit investment and operating costs, or alternatively would require excessive investment in transmission facilities in order to distribute over a widespread area from some centrally located plant. In either case a relatively high amount of reserve capacity would be needed to insure the reliability of the service. The advantageous position of the electric utilities with their large and economical plants at many load centers, and large-capacity transmission facilities generally available at other load centers not directly served by generating plants, is obvious.

Status of Electrification

Notwithstanding the fact that steam railroads have had the possibility of using electric traction available to them for many years, they have not found it feasible to utilize this form of power except for the few special cases to which we have referred. The reason for this has been stated to be the large new investment which would be required. It would be appropriate to add practical illustrations of the net results of operation before and after electrification, taking account of the changes in capital investments and all other factors affecting the net results. Unfortunately most of the comparisons available to the public deal in generalities or apply only to a specific phase of the subject. Furthermore, any comparison would be entirely dependent on the circumstances of the case, and would vary widely between different roads, or divisions of the same road, depending on traffic, profile, speed, and many other conditions.

Comprehensive data on the results of electrification have been published for the Chicago, Milwaukee, and St. Paul Railroad, and a recent analytical study of all the factors affecting the total net results of the Italian Railways may be found in Mr. Carli's report to the 1938 World Power Conference on "Comparative Results of Operations of Italian Steam and Electric Railways for the Year 1936–37" (*Elettrotecnica*, April 25, 1939). From the latter we can draw the conclusion that, apart from other important advantages *unrelated to the operating costs*, their savings by the use of electric traction are mainly due to the high cost of coal in Italy and would disappear entirely if their cost of coal were the same as in the United States. These conclusions are arrived at by a comparative analysis of Mr. Carli's tabulation, for the steam and electric systems, of all expense items that relate to the supply of power and operation of the transportation department, including interest charges on investment in locomotives and power equipment.

The aggregate expense per ton mile of steam traction was 17 per cent higher than for electric traction. Unfortunately Mr. Carli's study compares steam traction with electric under great differences in density of traffic; the electric lines with only one-third the mileage of the steam lines, carried 17½ billion ton miles against 21½ billion ton miles carried by the steam lines. This fact greatly favors the electric-traction system, and seriously limits the absolute value of the comparisons, although the relative value of the conclusions reached above are not disturbed. In analyzing the items of expense we find that the cost of coal was of the order of $8.70 per short ton. The equivalent cost for the class I railroads in this country was about $2.43, this low average price being partly due to the Interstate Commerce Commission accounting system which excludes from fuel expenses any cost or charges for its transportation on the reporting company's lines. But even if a liberal allowance were made for such charges, the American price per ton of fuel would have been less than one-half that of the Italian Railways. If the price in Italy had been on the same relative basis as in America the excess cost of steam traction would have been eliminated entirely.

The electric lines handled the 17.5 billion ton miles with an average consumption of 43 watt-hours per ton mile or a total of 750 million kilowatt-hours. Of this total the railways generated about one-fourth in four hydroelectric stations owned by the State, and purchased three-fourths from the utilities at 42 high-voltage delivery points. These results give a practical confirmation of the conclusions reached under the heading of "Underlying Economic Factors" and emphasize the fact that such economies are secured jointly with an infinitely greater insurance of continuity of service which is provided, not only by the large number of high-voltage delivery points, but also by the numerous generating plants back of them, which insure the supply of the utilities under abnormal conditions of operation.

Future Possibilities

Up to 1937 the railways in the United States had only electrified to the extent of consuming 1,627 million kilowatt-hours, which is estimated to be less than 2½ per cent of the total business. This would indicate that, under present conditions and prevailing prices of coal, electricity has not demonstrated definite advantages over steam traction except in a very few special cases where other considerations unrelated to operating costs might have influenced the change or where heavy traffic conditions and relatively high operating speeds prevail. We need considerably more analytical information to clarify the problem as to why the largest industry in this country has not adopted electric traction more widely. For the present, therefore, it is impossible to make any sound forecast of its probable growth. We must, however, bear in mind that changes in this country are apt to be rapid and powerful and that the utilities may eventually find in the railways a field for steadily expanding their power sales. The theoretical demand for such services, if all the railways were to be electrified would be of the order of three-fourths the present output of the entire central-station industry in the country. Only a third of this potential total would be as large as the present consumption of all residential consumers.

There are many obstacles in the way of further electrification which are not related to the cost of electric power but, to the extent that this cost influences the whole problem, the utilities have demonstrated that the railways can buy electricity from them more advantageously than they can secure it in an alternative way. In securing this business the utilities would be benefiting all their customers, because the economies realized from service to the railways ultimately accrue to the advantage of all users of electricity.

Discussion

Discussion will be found in the 1940 annual Transactions volume and in the 1940 "Transactions Supplement" to Electrical Engineering.

Overcurrent Performance of Bushing-Type Current Transformers

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Synopsis: Conventional methods used for defining and comparing current-transformer performances are commonly based on their ratio and phase-angle characteristics. For years, these characteristics have been continuously improved, particularly with respect to the requirements for metering service. However, from the standpoint of circuit protection, current-transformer application becomes more involved and as a result, increased attention has been given it.

A better knowledge of transformer performance is necessitated by the requirements of new relays and protective schemes. Attention to the influence of the d-c component in short-circuit transients is especially necessary when using high-speed relays. Also, in differential connections, the necessity for equivalent matching of saturation characteristics is essential. These are illustrations of the types of problems which ratio and phase-angle characteristics alone do not solve. The analysis of open-circuit saturation curves has proved of immense value in the solution of these problems.

This paper gives results of investigations on bushing-type transformers that indicate the proper choice of analysis procedure and the limitations of the various methods for determining performance under overcurrent operating conditions.

THE PURPOSE of this paper is to present the results of an investigation on the scope and limitations of saturation and loss curves in the application of bushing current transformers to relaying problems involving the overcurrent performance. The investigation covered the method of taking such data, the methods of calculation and the accuracy of ratio and phase-angle performance as calculated from it, and the application of the data to simplification of relaying problems.

The use of voltage-saturation and watt-loss data to analyze the performance of magnetic circuits has always afforded a means of predetermining the performance of devices associated with such circuits. Generators, transformers, and similar devices have their basis of design on these known characteristics of the magnetic material used. This leads to simplicity of investigation for a given set of conditions, and provides information which otherwise could be obtained only with the conditions peculiar to the investigation.

Within certain limitations it should be possible to formulate a practical analysis of the overcurrent performance of bushing-type current transformers in terms of the induced voltage and associated losses in a specified magnetic circuit independent of the operating conditions. The latter would be specified in terms of ratio, secondary burden, and primary-current range. These characteristics, if given in a desirable form, should be as suitable to the application engineer as they have been to the design engineer, and should find a wide range of usefulness.

Transformer Performance Characteristics

The conventional method for defining and comparing the performance of current transformers has been their ratio and phase-angle characteristics. Considerable information has been published relative to the improvement of these characteristics, particularly over the ranges of load currents and burdens encountered in metering service. These characteristics, particularly ratio, have been extended to cover the higher ranges encountered in relaying service.

With the advent of new relays and protective schemes the application of current transformers has become more involved, and the use of the conventional performance data has often proved inadequate for successful solution of certain types of these problems. Recently much progress has been made in application of high-speed relays[2,1] with the attending problem of transient performance by the use of open-circuit saturation curves. Many have found this criterion of great benefit in the solution of problems involving the overcurrent performance of bushing-type current transformers.

Saturation and Loss Data and Vector Diagram

A theoretical consideration of the vector diagram of the current transformer figure 1, which is the same as that for the conventional voltage transformer, shows that in general the primary constants of resistance and leakage reactance do not influence the performance, except by virtue of the indirect influence of the primary upon the secondary leakage reactance.[1] The difficulty of separating these leakage reactances is well known, and any effective use of the open-circuit saturation curve for calculating performance requires a knowledge of the approximate value of this reactance. For through-type current transformers with a ring-type core, symmetrically spaced, distributed secondary winding, and reasonably spaced primary conductor, the secondary leakage for low and medium core densities is sufficiently small that it can be neglected.[1,4] The usual bushing-type current transformer fits these requirements and hence the open-circuit saturation curve and equivalent circuit should lend themselves to the simplification of many problems involving the knowledge of its performance.

Method of Measuring Excitation Characteristics

Of the numerous methods of obtaining saturation and loss data on current transformers, the direct measurement of these quantities on the secondary winding with the primary open-circuited has been chosen for its simplicity, flexibility, and economy. It has been found when making such measurements that the wave shapes of the currents and voltages, and the types of measuring instruments used have a direct bearing on the results. Previous experience indicated satisfactory calculations of transformer performance could be made from saturation and loss data taken by impressing sine wave voltages and measuring the rms voltages and currents.

As it is often difficult to determine and maintain wave form when obtaining saturation and loss data, tests were made to determine the influence of wave shape. A 600/5 multiratio bushing current transformer for a 138-kv oil circuit breaker was tested; first, using sine-wave impressed voltage, and second, circulating sine-wave exciting current. As illustrated by figure 2, both voltage and current are essentially sine wave for core densities below saturation, while either one or the other, or both, must be distorted when the core becomes saturated. The results obtained throughout the complete range of core densities are shown in figure 3. These curves also indicate, when using sine-wave

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2. For all numbered references, see list at end of paper.

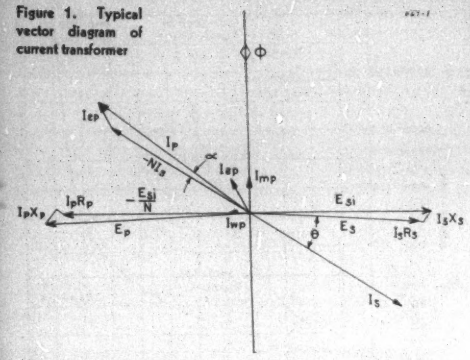


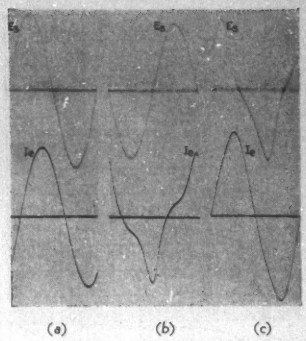
Figure 1. Typical vector diagram of current transformer

Figure 2. Typical oscillograms of current-transformer saturation characteristics

(*a*)—Sine-wave voltage and current—medium flux density

(*b*)—Sine-wave voltage—saturated density

(*c*)—Sine-wave current—saturated density



(*a*) (*b*) (*c*)

exciting current, the difference in results from measuring the voltage with a repulsion-iron voltmeter which reads rms voltage, and the Rectox voltmeter which reads the average voltage multiplied by the form factor 1.11.

It will be noted that there is quite close agreement between the sine-wave voltage and sine-wave current excitation curves, when the voltage, in the latter case, is measured with a Rectox voltmeter. This is in accordance with accepted practice, as it is known, that for a distorted voltage wave having the same average value as a given sine wave voltage, the maximum flux is equal. The equal values of maximum flux represent equivalent flux conditions independent of wave shape.

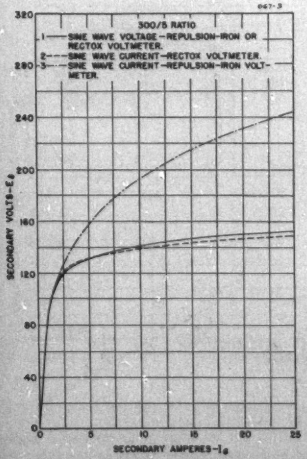


Figure 3. Saturation characteristic curves taken at sine-wave voltage, and at sine-wave current

Under operating conditions the primary current of the transformer is essentially a sine wave. Through the lower-density range the exciting currents, secondary induced voltages, and burden currents are all approximately sine waves. In the saturated region all of these quantities are somewhat distorted. However, the errors introduced by these harmonics are relatively unimportant unless they are large, and then only when the total exciting current is an appreciable portion of the primary current. These conditions are illustrated by the oscillograms of figures 4*a*, *b*, and *c*.

It appears from a practical operating viewpoint that saturation tests may be made independent of wave form when using rms ammeters and voltmeters responding substantially to average voltage but with an rms sine-wave calibration. Such data will give sufficient accuracy for most performance calculations.

Effects of Primary and Secondary Winding Locations on Performance

In an effort to determine the effect of and variations in the secondary leakage reactance of bushing transformers at high values of overload currents, conventional ratio and phase-angle tests were made on several oil-circuit-breaker transformers. The standard multiratio transformer has the total secondary winding well distributed over the core, but the various lower ratios are obtained by means of tapping portions of the secondary winding, resulting in relatively poorer distribution on the low and intermediate ratios.

From a theoretical viewpoint the variation of secondary leakage with the position of secondary winding is increased with closer proximity of the primary return conductor, with higher magnitudes of primary current, with greater asymmetry of the secondary winding, and with increased core diameters. In this investigation the transformers were tested with the approximate spacing of the primary conductor as encountered in practice, and with two different positions of secondary winding with respect to the primary return as shown by positions *AA* and *BB* of figure 9. Position *AA* represents the middle axis of the secondary winding in a relation to the return conductor which gives the condition of mini-

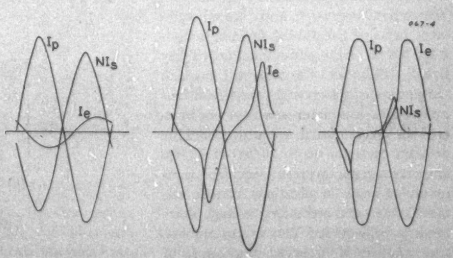


Figure 4. Reproduced oscillograms showing wave shape of primary, secondary, and resultant exciting currents with a secondary burden of 50 volt-amperes, 100 per cent power factor

(*a*)—Medium flux density (*b*)—High flux density (*c*)—Saturated flux density

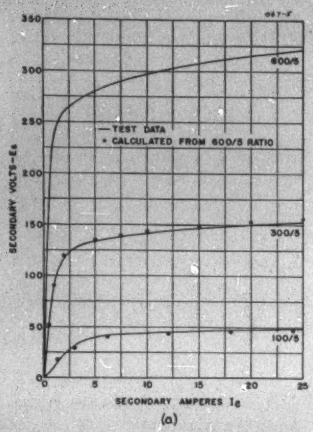


Figure 5 (left). Saturation and watt loss characteristics of a current transformer

(*a*)—Voltage versus exciting current

(*b*)—Wattloss versus exciting current

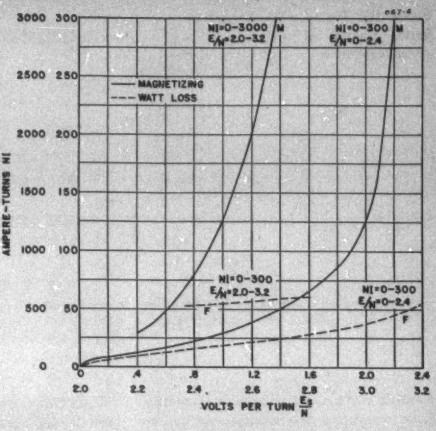
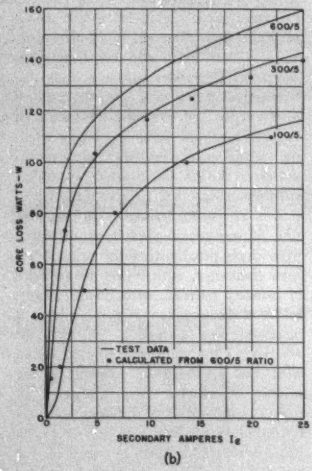


Figure 6. Ampere-turn versus volt-per-turn characteristics of bushing current transformer of figure 5



mum coupling, and likewise position *BB* gives a maximum coupling.

These tests, typical results of which are shown by figures 9*a*, *b*, and *c* are not sufficient in scope to establish definite boundaries for all of the parameters previously listed. However, for standard bushing current transformers with core dimensions and return conductor spacings encountered in conventional apparatus, and for primary currents up to 25,000 or 30,000 amperes, satisfactory results in calculations involving relay applications can be obtained when the secondary leakage reactance is neglected. This is particularly true when it is observed that most of such applications use performance data based on nonsaturating burden impedances, which is, at times, coarsely modified to meet actual operating conditions.

Various Forms of Saturation and Loss Curves

The saturation and loss data taken under the conditions previously outlined result in a set of data as shown in figures 5*a* and *b* for various ratios. The data thus taken can be shown in several different forms, and may be converted into similar data for any other ratio using the same magnetic core. Two forms are indicated by the curves of figures 5 and 6, and the methods which can be used for these conversions are given in appendix II. The first form gives voltage and watt loss versus exciting current in secondary terms for a given ratio, while the second form gives the core loss and magnetizing components on an ampere-turn versus volts per turn basis which is independent of the ratio.

Attention is directed to the curves in figure 5, where the full-line curves are plotted test data, while the indicated points on the 100/5 and 300/5 ratios are conversions from the 600/5 data using equations 10, 12, and 13 of appendix II. These curves indicate that very satisfactory transformations from one ratio

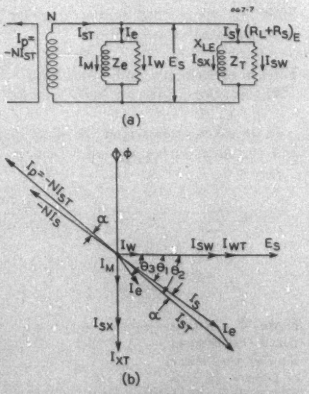


Figure 7

(*a*)—Equivalent circuit of current transformer on secondary base

(*b*)—Vector diagram of (*a*)

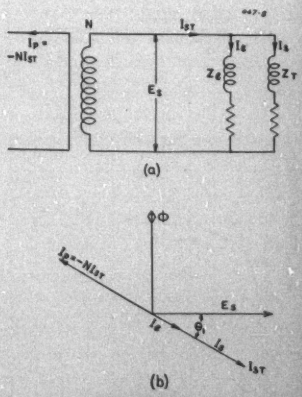


Figure 8

(*a*)—Simplified equivalent circuit of current transformer on secondary base

(*b*)—Vector diagram of (*a*)

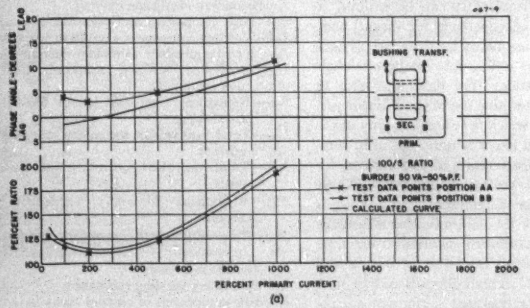
to another may be made, the greatest source of variation coming from the use of commercial rather than precision testing facilities. Figure 6 is another form of expressing the data as calculated by equations 4 to 8 of appendix II. In this form they may be considered the master curves since they give the fundamental data which can be used to calculate the saturation and loss curves, and other calculations based on these data for any ratio using the same core. Since bushing current transformers have only the single primary turn, the ordinates for the magnetizing and loss ampere turns of figure 6 could be conveniently called primary amperes.

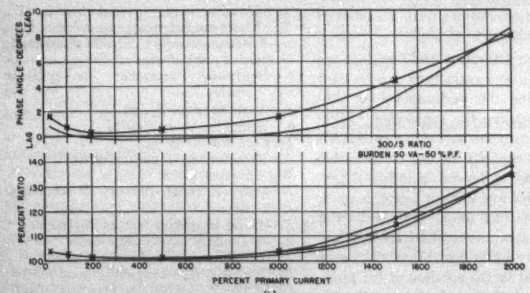
Calculation of Ratio and Phase-Angle Performance

The formulas for the calculation of transformer performance from the saturation and loss curves are given in appendix III. These calculations may be divided into two classes; the first giving both ratio and phase angle, and the second giving approximate ratio. In this connection it is interesting to note the theoretical effect of burden power factor on the phase-angle error of the transformer, as illustrated by figure 7. For lagging burdens the maximum possible phase angle error for any degree of saturation is less than 90 degrees and decreases with decreasing burden power factor, but in practice seldom exceeds 30 or 40 degrees. With unity or leading power factor burdens the phase-angle error may approach 90 degrees. Hence, for burdens having very lagging power factors the second method of calculation gives good results.

The agreement between the first method of calculation and test data is indicated in figures 9*a*, *b*, and *c* which show the comparison between calculated and actual test performance. As indicated, there is a difference between the results which occur for the following reasons:

1. Neglect of secondary leakage reactance which has been previously mentioned.





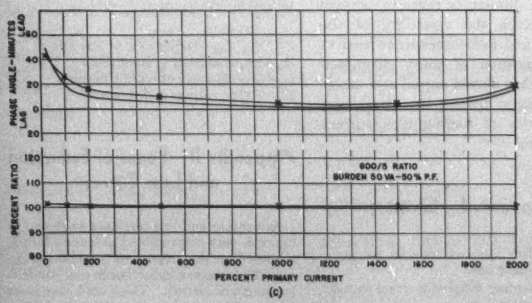
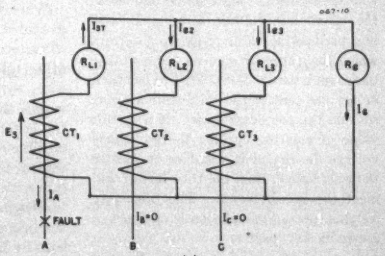


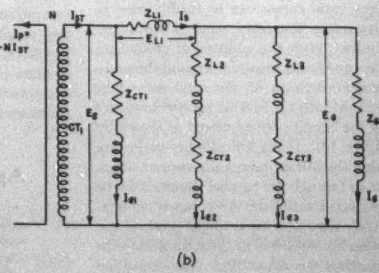
Figure 9 (left). Ratio and phase-angle calculated and test characteristic curves of current transformer

(*a*)—For 100-to-5 ratio
(*b*)—For 300-to-5 ratio
(*c*)—For 600-to-5 ratio

Figure 10

(*a*)—Typical three-phase relay circuit
(*b*)—Equivalent circuit for (*a*)





2. Neglect of harmonics, particularly with respect to their effect on the phase-angle error. The null test method used to obtain the phase angle compares the fundamental-frequency components of the secondary and primary currents, while the method of calculation has assumed all quantities are of fundamental frequency.

3. The order of accuracy of test data, including both saturation and loss data, as well as ratio and phase-angle data. Test errors could be reduced to a minimum by increasing the precision of the testing facilities. However, the work described herein was done with ordinary commercial testing equipment in order to observe the limitations which might be imposed on the use of saturation and loss data in practical applications.

Application to Relay Problems

In a large number of applications it is only necessary to determine if the degree of linearity of the transformer performance with a given burden over a specific range of primary current is within required limits. A glance at a saturation curve such as shown in figure 5*a* enables one to estimate quickly the limits over which approximately linear performance will be obtained. This can be defined as the maximum voltage obtainable with any permissible value of exciting current which may be expressed on a percentage basis, such as two per cent, five per cent, or ten per cent of the total primary current on the secondary base. If with this value of exciting current the secondary voltage developed is equal to or greater than necessary, then the transformer will meet the requirements. The procedure for this form of calculation is outlined in appendix III, part *c*.

In a simple three-phase circuit with overcurrent or directional overcurrent relays, ratio curves can be readily used to determine the relay settings for phase faults. With the addition of ground relays and faults involving ground the problem of division of the total secondary current into the several parallel branches of the circuit is encountered as shown by figure 10. If the transformer ratios are high (high impedance) the current which leaks through the parallel circuits may be neglected with little error, but when relatively low ratios are involved this problem often becomes quite serious, resulting with incorrect relay operation. The saturation curve lends itself admirably to the solutions of problems of this nature as outlined in appendix IV. It will be evident that additional refinements can be made on this method by taking into account the vector relationships and all of the circuit constants. Again, in cases involving the paralleling of transformers of two or more circuits, similar problems of leakage of the secondary current through the multiple circuits and the effective burdens are encountered.

Conclusions

From the foregoing it is evident that the open-circuit a-c saturation and loss data will be extremely useful in the field of relay application. It can be utilized to determine relay settings for various magnitudes of secondary burdens and primary currents, as well as ratio and phase-angle characteristics. The data may also be used to determine the range of linear performance, which is valuable in any application, and is particularly useful in comparing characteristics of transformers for differential protection schemes. Where a knowledge of the exciting impedance is required for the determination of leakage currents in branch circuits, it may be easily obtained from the saturation and loss curves. This information, like that required for transient performance, cannot be readily obtained from the conventional performance curves.

When the saturation and loss data are available on any ratio they can be used to determine the performance on any other ratio using the same core. Likewise, they can be used for any burden within the capacity of the transformer; the latter when defined in terms of permissible error and current range, is quite evident from such data. This is not the case with ratio curves where the application engineer, in the field, often is seriously handicapped in the solution of his problems by the lack of ratio data on the desired ratio, burden, or range of primary current. Since the versatility of the saturation and loss curves lends itself to the simplification of many diversified problems, they should appeal as a means of more clearly defining the overcurrent characteristics of bushing-type current transformers.

Appendix I—Glossary

E_{si}—Secondary induced internal voltage—secondary base
E_{si}/N—Secondary induced internal voltage—primary base
E_p—Primary terminal voltage
E_s—Secondary terminal voltage
E_s/N—Volts per turn
E_{sk}—Secondary voltage of transformer at a specified exciting current
I_sX_s—Secondary leakage reactance drop
I_pX_p—Primary leakage reactance drop
I_sR_s—Secondary winding resistance drop
I_pR_p—Primary winding resistance drop
I_s—Secondary burden current
I_{sk}—Permissible value of excitation current for a secondary voltage E_{sk}
NI_{ST}—Total secondary current—primary base
NI_S—Secondary burden current—primary base
I_{ep}—Core excitation current—primary base
I_{wp}—Core excitation watt component of current—primary base
I_{mp}—Core excitation wattless component of current—primary base
I_p—Primary current
I_e—Secondary excitation current
I_W—Watt component excitation current
I_M—Wattless component excitation current
I_{ST}—Total equivalent secondary current
I_{SX}—Equivalent wattless component burden current I_S
I_{SW}—Equivalent watt component burden current I_S
I_{XT}—Total equivalent secondary wattless current
I_{WT}—Total equivalent secondary watt current
X_{LS}—Equivalent secondary burden reactance
$(R_L+R_S)_S$—Equivalent secondary burden resistance
R_L—Burden resistance
R_S—Secondary winding resistance
F—Watt component of ampere turns
M—Wattless component of ampere turns
T_n—Times normal voltage or current
α—Primary-secondary current phase angle
θ—Burden power-factor angle
θ_1—Equivalent secondary power-factor angle
θ_T—Angle between E_s and I_{ST}
θ_E—Excitation current angle
ϕ—Core flux
N—Transformer secondary turns
W—Core loss watts
NI—Ampere turns—primary or secondary base
Z_T—Total secondary burden impedance
Z_S—Secondary burden impedance
Z_s—Open-circuit transformer impedance
R_{L1}, R_{L2}, R_{L3}, R_G—Line and ground relays
CT_1, CT_2, CT_3—Bushing current transformers
I_A, I_B, I_C—Line currents of a three-phase system
Z_{L1}, Z_{L2}, Z_{L3}—Impedance of line relays
Z_G—Impedance of ground relay
I_G—Ground-relay operating current
E_G—Relay voltage at I_G current

Appendix II—Forms of Saturation and Loss Curves

Saturation and loss test data as shown in figure 5, may be presented in several forms, all based on the ampere-turn excitation required for a given induction in any particular magnetic circuit. These data have been taken with open-circuit primary, reading the impressed voltage and watts loss at specified values of secondary circulated current. The induced voltage is taken equal to the impressed voltage, since the resistance drop of the winding is of small magnitude and becomes negligible when considered in its vector relation to the impressed voltage. The watt loss of the secondary winding is ap-

preciable in comparison to the core loss and the observed data has been corrected to take this into account. Hence:

$$E_{s1} = E_s \tag{1}$$

At a given voltage E_s for N turns, the exciting current is I_e, figure 5a, and the exciting volt-amperes are:

$$E_s I_e \tag{2}$$

At this current I_e the core loss is W watts, figure 5b. The angle between E_s and I_e as shown by figure 7b is θ_3 and is expressed:

$$\theta_3 = \cos^{-1}\frac{W}{E_s I_e} \tag{3}$$

The exciting current is divided into its magnetizing and loss components I_M and I_W respectively:

$$I_M = I_e \sin\theta_3 \tag{4}$$

$$I_W = I_e \cos\theta_3 \tag{5}$$

The data may then be interpreted in values independent of the secondary winding.

$$\text{Induction} = \frac{E_s}{N} \text{ volts per turn} \tag{6}$$

$$\text{Excitation} = NI \text{ ampere turns} \tag{7}$$

The excitation in ampere turns is the same on either primary or secondary turn basis, and since the bushing transformer has only one primary turn it follows that:

$$I_{mp} = NI_M = M$$

and

$$I_{wp} = NI_W = F \tag{8}$$

By the use of equations 4 to 8 a set of data for a given ratio and core as represented by figure 5a and b may be converted into the general form as given by the curves in figure 6.

Another convenient form of interpreting these test data as obtained on one ratio N_1 to another ratio N_2 is shown by the curves for the 100 to 5 and 300 to 5 ratios in figures 5a and b; and is derived on the following basis:

For a given voltage E_{s1} and loss W_1 on turn basis N_1 with exciting I_{e1}:

$$N_1 I_{e1} = N_2 I_{e2} \tag{9}$$

Therefore:

$$I_{e2} = \frac{N_1}{N_2} I_{e1} \tag{10}$$

Likewise the induced voltage per turn:

$$\frac{E_{s1}}{N_1} = \frac{E_{s2}}{N_2} \tag{11}$$

Therefore:

$$E_{s2} = \frac{N_2}{N_1} E_{s1} \tag{12}$$

and

$$W_2 = W_1 \tag{13}$$

By the use of equations 10, 12, and 13 the curves for the 100-to-5 and 300-to-5 ratios as shown by the indicated points in figures 5a and b are calculated and the agreement with test values is well illustrated.

Appendix III—Calculation of Performance Characteristics

(a) Ratio and Phase Angle

The calculations are based on the equivalent circuit and diagram figure 7, which refers all quantities to the secondary side and includes consideration of the vector relationships. Assume a burden Z_B at a power-factor angle θ_s, current I_S, and ratio N. The total burden Z_T includes the secondary winding resistance R_S. Hence:

$$Z_T = (R_B + R_S) + jX_B \tag{14}$$

$$\theta_1 = \cos^{-1}\frac{R_B + R_S}{Z_T} \tag{15}$$

Also the secondary voltage required:

$$E_s = I_S Z_T \tag{16}$$

For this voltage the excitation current I_e is required and obtained from the saturation and loss curves. These currents are then separated into their watt and wattless components, and added vectorially as indicated in the equivalent circuit and vector diagram of figure 7, with the following equations:

$$I_{SW} = I_S \cos\theta_1 \tag{17}$$

$$I_{SX} = I_S \sin\theta_1 \tag{18}$$

The values for I_W and I_M are obtained from the curves of figure 6 for the induction E_s/N.

Therefore:

$$I_p = \frac{F\,(\text{from figure 6})}{N} \tag{19}$$

$$= I_e \cos\theta_2 \text{ (from figure 5a)}$$

and

$$I_M = \frac{M\,(\text{from figure 6})}{N} \tag{20}$$

$$= I_e \sin\theta_2 \text{ (from figure 5a)}$$

$$I_{WT} = I_{SW} + I_W \tag{21}$$

$$I_{XT} = I_{SX} + I_M \tag{22}$$

$$I_{ST} = \sqrt{I_{WT}^2 + I_{XT}^2} \tag{23}$$

$$I_p = NI_{ST} \tag{24}$$

$$\text{Per cent ratio} = \frac{I_p(100)}{I_S N} \tag{25}$$

Substituting (24) in (25) and collecting terms:

$$\text{Per cent ratio} = \frac{I_{ST}(100)}{I_S} \tag{26}$$

$$\text{Per cent primary current} = \frac{I_p(100)}{\text{Rated primary current}} \tag{27}$$

Phase angle is:

$$\alpha = \theta_2 - \theta_1 \tag{28}$$

where $\theta_2 = \tan^{-1}\frac{I_{XT}}{I_{WT}}$ (29)

and θ_1 is given by equation 15.

(b) Simplified Method

The calculations are based on the equivalent circuit and diagram, figure 8, and assume all quantities to be scalar values in phase with the secondary current. These quantities are referred to the secondary side. The justification for this method is based on the fact that relaying burdens usually have low power-factor angles approaching the excitation angle. Thus the calculated results will indicate poorer ratio performance than obtained in service, and will disregard the phase-angle performance. Under these conditions:

$$E_s = I_S Z_T \tag{30}$$

where Z_T is obtained from equation 14.

The total secondary current is:

$$I_{ST} = I_S + I_e \tag{31}$$

where I_e is a value of exciting current obtained from a saturation curve similar to figure 5 for a given ratio N at voltage E_s. The primary current, per cent ratio, and per cent primary current are then obtained by equations 24, 26, and 27 respectively.

(c) Linear Performance Range

The determination of the linear performance range of a current transformer may be ascertained from a saturation curve by assuming an allowable percentage P of maximum primary current I_p for the core excitation current I_{ek}. The exciting current on the secondary base becomes

$$I_{ek} = \frac{I_p}{N} \times \frac{P}{100} \tag{32}$$

The value of voltage on the saturation curve corresponding to the current I_e for a given ratio N, yields a developed voltage E_{sk}. Comparing the burden voltage E_s at rated secondary current with the value E_{sk} indicates the number of times normal T_n, that the transformer will function linearly, or

$$T_n = \frac{E_{sk}}{E_s} \tag{33}$$

With I_p taken as the maximum primary current and $5N$ as the normal primary-current rating, then if, $T_n > I_p/5N$, the transformer provides linear performance over the considered range. If $T_n < I_p/5N$, this indicates that the ratio error is greater than the permissible assumed value P per cent and requires recalculation on basis of lower primary current.

Appendix IV—Application of Saturation Curve to Typical Relay Problem

A typical problem involves the relay protection of a three-phase circuit with grounded neutral using phase and ground-current relays as shown in figure 10. Assume line-to-ground fault current in phase A, and no current in phases B and C, then

the equivalent circuit for the three-phase circuit is as shown in figure 10*b*. Current transformers CT_1 and CT_3 in series with their respective line relays form leakage-current paths in parallel with the ground relay which may appreciably reduce the current I_G in the relay.

Assume the ground relay tap setting requires an operating current I_G, and following the practice outlined in appendix III, part *b*, wherein all quantities were considered scalar and in phase, the following procedure may be used to determine the approximate value of primary current required to operate the relay.

$$E_G = I_G Z_G \tag{34}$$

Since Z_{L3} and Z_{L4} are usually small compared to the transformer impedance, they may be neglected thus avoiding the complication of using a cut-and-try method to determine the total value of $(Z_{L3}+Z_{CT3})$. The result of neglecting the impedance of these relays will be in favor of the ground relay.

$$I_{e3} = I_{e4} \tag{35}$$

These values may be obtained from a saturation curve such as shown in figure 5*a* for the voltage E_G on a ratio N.

$$I_3 = I_G + 2I_{e3} \tag{36}$$

$$E_{L1} = I_3 Z_{L1} \tag{37}$$

$$E_2 = E_{L1} + E_G \tag{38}$$

It then follows that the required excitation current I_{e1} for CT_1 may be obtained as previously noted for voltage E_2.

Then

$$I_{ST} = I_3 + I_{e1} \tag{39}$$

and

$$I_p = NI_{ST} \tag{40}$$

This last equation gives the approximate primary current required to obtain the ground relay current I_G.

Bibliography

1. **H. W. Price and C. Kent Duff**, papers on current transformers, University of Toronto Bulletin No. 2, 1921, section number 4.

2. CURRENT-TRANSFORMER EXCITATION UNDER TRANSIENT CONDITIONS, **D. E. Marshall and P. O. Laagguth.** AIEE JOURNAL, volume 48, 1929, pages 1464-74.

3. CURRENT TRANSFORMER AND RELAYS FOR HIGH-SPEED DIFFERENTIAL PROTECTION WITH PARTICULAR REFERENCE TO OFFSET TRANSIENT CURRENTS, **R. C. Wentz and W. K. Sonnemann.** AIEE TRANSACTIONS, volume 59, 1940 (August section), pages 481–8.

4. NEW DEVELOPMENT IN CURRENT-TRANSFORMER DESIGN, **O. Camilli.** AIEE TRANSACTIONS, volume 59, 1940 (see annual index).

5. INSTRUMENT TRANSFORMERS (a book), **B. Hague.**

Discussion

Discussion will be found in the 1940 annual TRANSACTIONS volume and in the 1940 "Transactions Supplement" to ELECTRICAL ENGINEERING.

Power Supply for Railroad Electrification and Fundamentals of Power Contracts

E. R. HILL
FELLOW AIEE

THE PURPOSE of this paper is to indicate and clarify the status of the American railroad as a major factor in the generation and use of power, the extent to which steam-railroad electrification has become an element therein, the effect of electric-power costs on the extension of railroad electrification, and the desirable features of power contracts in connection with such electrification.

Railroads as Producers and Users of Power

Before the advent of the electric street and interurban railway and the use of electricity for domestic and industrial lighting and power purposes, the railroads of the country were the large producers and users of power, of course developed in many relatively small steam-locomotive units. That power business has grown until in 1937 the aggregate indicated horsepower of locomotives in service on the 136 class I railroads (roads with operating revenues of more than $1,000,000 a year) amounted in round figures to 100,000,000 horsepower. This compares with an aggregate installed capacity of all utility plants—hydro and steam—of approximately 50,000,000 horsepower.

Extent of Railroad Electrification

There are approximately 250,000 miles of railroads in the United States of which 235,000 miles are in the class I group. Of this total only 1.3 per cent have been electrified (6 per cent in the rest of the world). This, however, represents a considerable mileage, namely 2,965 route miles (6,950 miles of track) distributed over 24 railroads. The main reason for this relatively slow progress is the high capital cost of electrification because of which operating savings do not result in a sufficiently quick payout to virtually compel electrification.

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Advantages of Electrification

Electrification permits operating accomplishments that are not possible with steam power; it increases the capacity of a given railroad thus frequently saving large expenditure for additional trackage or terminal facilities; it adds to the attractiveness of the service and the comfort of the public; and through operating savings usually more than pays fixed charges. Thus it is conspicuous in being a type of railroad betterment that provides many desirable facilities and at the same time "pays its way." Among the outstanding operating benefits are great reliability of operation, high degree of availability and serviceability of the traction units, and the almost unlimited amount of power that may be made available for the movement of traffic. Underground terminals and connecting tunnels would be impracticable without electrification and capacity limitations of long mountain tunnels are overcome thereby.

Today probably the greatest demand on transportation is for service and the above advantages, together with the high operating speeds attainable, make electrification a valuable factor in enabling railroads to meet this requirement.

Operating Savings Due to Electrification

The major elements of operating cost, wherein savings by electric power as compared with steam are effected, include:

Locomotive repairs. These are considerably lower under electric operation and constitute one of the largest items of saving. Engine-house expenses, inspection, etc., may be included in this general group and in these substantial savings are effected.

Transportation costs enter into the picture—these savings are substantial when the improved operation with electric power can be fully realized and the service can be rendered with a smaller number of larger train units.

Miscellaneous and indirect savings usually aggregate a substantial sum.

Cost of electric power versus locomotive fuel is an important item. Under some conditions this cost makes the project unattractive and becomes a controlling consideration from the standpoint of operating costs and savings.

Advances in the Art

The major advances in the art of power production as affecting efficiency and cost have been in the conversion of the heat energy in fuel into mechanical energy, where the efficiency has always been relatively low. The efficiency of conversion of mechanical into electrical energy is already high and little improvement has occurred or can be expected here.

During the period of great improvement in boilers, furnaces, and prime movers due to more efficient combustion methods, higher pressures, and superheat and other advances in the design of steam-electric generating plants parallel progress has been made in the efficiency of the steam locomotive. Thus in the past 15 or 20 years, there has been a reduction of about 25 per cent in the coal consumption on steam railroads per transportation unit. In the same period, as shown by the Federal Power Commission's statistics, there has been a reduction of nearly 50 per cent in coal burned per kilowatt-hour in steam-electric power plants of the utility companies. These figures indicate that in so far as efficiency of conversion of fuel into mechanical energy is concerned, the stationary plant still has the advantage.

Public-Utility Supply Versus Railroad Generating Plants

In the early days of railroad electrification, including that of terminals and certain city transit lines, it was found economical or necessary for the railroads to build their own power plants. The characteristics of the supply—frequency, phase, amount and fluctuating character of loads, etc.—and the rates quoted by utilities for such supply indicated in many cases that substantial savings would result from the railroad building its own plant. An important part of this advantage is that the railroad plant is built to produce the kind of electric power required without conversion from 60 cycles and it can be conveniently located with respect to the railroad's load center. Latterly, some of these plants have been leased or otherwise taken over by the utilities and purchased-power contracts substituted for railroad generation. In connection with most of the larger and more important railroad electrifications, power in whole or in part is now purchased from the utility companies.

Characteristics of Railroad Load

All railroads, both in the United States and abroad, use for traction purposes current of other characteristics than 60 cycles three phase that now is the general standard in this country for commercial power systems. This means that converting equipment of some kind is necessary to produce either direct current or 25-cycle single-phase current required for railroad operation. Development of the static converter type of equipment for frequency changing may result in increased efficiency of conversion and ultimately in lower cost of such equipment.

On the shorter railroad electrifications, such as for terminal operation or for mountain-grade lines, because of heavy train units and other operating conditions the demand on the supply system fluctuates widely. In some cases also the peak loads frequently occur at irregular and unpredictable times. These, together with the characteristics of the current, are adverse conditions which tend to make the supply by the utility of such requirements somewhat difficult and relatively costly.

On the other hand, where the railroad electrification is extensive and the traffic dense and comprised of a large number of train units, the fluctuations are not unduly severe and the load factor is relatively high; also the heavy demands frequently occur at off-peak times with reference to the utilities' commercial load. These features are favorable and should tend to reduce the cost of supplying energy.

Supply From Several Utilities

On extensive electrifications where the electrified lines cover hundreds of miles of route and cut across territory normally served by a number of different utilities, it is usually necessary for the railroad either to choose between such utilities and provide its own transmission lines in addition to substations and trolley system or to enter into agreements with two or more of the utilities. In the latter case, the railroad's entire requirements must be covered and the rates should be so applied that the railroad pays on the basis of its system load factor; otherwise it will be penalized in regard to load factor due to dissimilar conditions in the different areas traversed.

In this connection it is interesting to note the effect the extension of electrification has had on the load factor which in turn affects the over-all cost of energy as illustrated by table I.

This table shows, as is well understood, that the load factor of the supply to purely suburban electrified lines is low because of the heavy morning and evening travel and relatively light load at other times of the day.

When this suburban service is supplemented by through passenger traffic or by both passenger and freight, there is a substantial improvement in load factor. When the through passenger and freight traffic becomes so extensive and heavy as to form the major portion of the load an excellent load factor results. Thus in the table the average monthly load factor gradually increased from 33 per cent for suburban traffic only to 62 per cent after the entire program of suburban and through electrification was carried out. If there had been no suburban electrification the average load factor due to through passenger and freight service would have been of the order of 75.

If the electrification had been divided into say three main sections the load factor for each section would have been lower and the sum of the peak loads or demands on which separate billings would be based would be of the order of eight to nine per cent higher than the actual system peak loads. This in the case above cited would have represented an additional power cost to the railroad of more than $200,000 a year.

The supply of power by several utilities at the railroad's system load factor can be made effective in either of two ways:

1. By the railroad installing transmission lines of sufficient capacity to interchange power and energy between the different areas, thus enabling each utility actually to deliver its share or quota of the total demand and energy requirements, through the railroad transmission lines, or,

2. By the utilities jointly contracting with the railroad and with each other to supply

Table I

Service Operated	Miles of Route Operated	Miles of Track Operated	Average Monthly Demand*	Load Factor (Per Cent)
Suburban only	130	400	37,000	33–34
Through passenger service added	180	600	60,000	46
Same, with through passenger service extended	350	1,300	76,000	48
Same, with through freight added	380	1,370	120,000	55
Same, with further extension of through passenger and freight service	675	2,190	141,500	62

* Based on three maximum clock hours per month.

the portion of the demand and energy actually drawn by the railroad in each area and combining or pooling the demand and energy and jointly billing the railroad.

Such utilities should be interconnected and operated in parallel on the 60-cycle side so as to maintain synchronism effectively and thus avoid momentary interruptions in the supply when trains pass from one area to another. Most of the utilities are already normally interconnected for their own operating and economic purposes and their lines often parallel important trunk lines of railroads in territory where the traffic is sufficiently heavy to warrant electrification. In some localities portions of the railroad right of way are utilized for transmission lines of the utility. Joint use of railroad electrification structures is also feasible in some cases.

It is desirable from the standpoint of cost of special equipment that the number of supply points should not be unduly multiplied. Broadly speaking, the power-supply system—railroad and utility—should be so planned as to involve the minimum total capital expenditure by the parties consistent with the requirements of the service.

In considering electric traction railroads are confronted with the high capital cost and are usually desirous of shifting to the utilities as much as possible of the cost of power-supplying equipment. Locomotives are at present usually purchased through equipment trusts, the money being borrowed at favorable interest rates largely independent of the credit status of the railroad. If a similar plan could be devised for financing the roadway power equipment at favorable rates, greater progress in railroad electrification might result.

Cost of Electric Energy

It is generally believed that a public utility engaged in generating and supplying electric power to all sorts of customers should be able to produce power at lower cost than can be done by a railroad in its own power plant or plants; also that utilities are willing to supply the railroads on the basis of actual cost, including a reasonable return on investment and, therefore, there should no longer be any question as to whether a railroad about to electrify should purchase its power or generate it. There are a number of considerations, however, that enter into this question and which have an important bearing upon the railroad's decision to buy power from the utilities on such cost basis. Amongst these are the rates covering fixed charges on capital investment which the utilities may find necessary to use in arriving at cost and which may for a number of reasons be relatively high.

Such factors coupled with the railroad's ability to generate in its own plant, conveniently located, the form of energy required to operate its trains, may in certain cases more than offset the lower cost to the utility of generating its standard form of electrical energy and then converting it for railroad use.

The trend in the average cost per kilowatt-hour for purchased energy has been downward for the past ten years or more in respect to residential, commercial, and interurban and street-railway business. There was no definite downward trend in the cost of energy purchased for steam-railroad electrification until 1935 and since then the reduction appears to have been mainly due to improved load factor or some other special conditions rather than the lowering of rates.

Power Contracts

Experience has shown that power contracts as between railroads and electric utility companies in order to be generally satisfactory to the railroads should provide for the following railroad requirements:

(*a*). The contract should be for a long term—say 20 years with renewal options—so as to amortize on a low rate basis the cost of special equipment. A longer term than 20 years would be permissible if the rates for demand and energy are on a "cost" basis thus assuring to the railroad the benefits of advances in the art.

(*b*). The utility should preferably, although not necessarily, provide and own the special equipment and supply the power at the phase, frequency, and possibly the voltage required for railroad operation. This would minimize the investment by the railroad but fixed charges on same should be on a low basis comparable with rates applicable to the railroad's own capital expenditures.

(*c*). It is preferable to the railroad for the utility or group of utilities to supply power at a sufficient number of points in the electrified zone to take advantage of the utilities' networks to reduce investment costs by the railroad and at the same time further assure reliability of the supply.

(*d*). While the railroads would like to purchase power on a flat or sliding rate per kilowatt-hour, much as they purchase fuel, it has so far been impracticable to work out such a basis and separate demand and energy rates are customarily used.

(*e*). Demand charges should be on a monthly basis and should be established by averaging three or more clock-hour peak loads in the month. In selecting such peak hours, those caused by abnormal and emergency conditions should be excluded. System peaks rather than sectional peaks should be used in determining the maximum demand. When railroad peaks regularly occur at utility off peak times such as between 9:00 p.m. and 7:00 a.m., this should be reflected in a fair way in the demand rate.

(*f*). The energy charge should be based on the summation of meter readings at all points and is properly subject to correction for fluctuations in cost of fuel. The demand and energy charges may be on agreed rates or they may be based on the actual cost to the utilities within upset or over-all limits, the elements of such cost being defined, the rate used in billings in any yearly period being based on the actual cost for the preceding year.

(*g*). Where a substantial portion of energy is generated in hydroelectric plants of either the contracting utility or its affiliates and is furnished on a cost basis a suitable correction factor should be applied because of the high first cost and low operating cost of such plants.

(*h*). Power contracts should be as simple as possible as to form and should eliminate all unnecessary conditions and stipulations that might lead to misunderstandings and disputes. No guarantee as to load factor should be required of the railroad, nor should guarantees as to the minimum demand charge following a previously established maximum be required. While minimum loads of two-thirds or three-fourths of the previously established demands have been stipulated in some railroad contracts, it is preferable from the railroad's viewpoint to eliminate such clauses. Wide variations are inherent in the nature of the traffic on trunk-line railroads and are quite beyond the control of the management. They should be understood and recognized by the utility but should not appear in the contract.

In conclusion, the writer would express the hope that the downward trend in the cost of generating and distributing electric power will presently be reflected in the rates offered for railroad electrification and will be on a scale which will make the cost of power one of the major items of saving by electrification. It is also the hope that at the same time ways may be found materially to reduce the capital cost of electrification. If these things can be accomplished, important pending projects may be undertaken with every assurance of attractive financial as well as operating results. In that case, power companies operating in the vicinity of newly electrified railroad lines would be assured of large additional blocks of load, and the best interest of two important groups of public servants would be mutually advanced.

Discussion

Discussion will be found in the 1940 annual TRANSACTIONS volume and in the 1940 "Transactions Supplement" to ELECTRICAL ENGINEERING.

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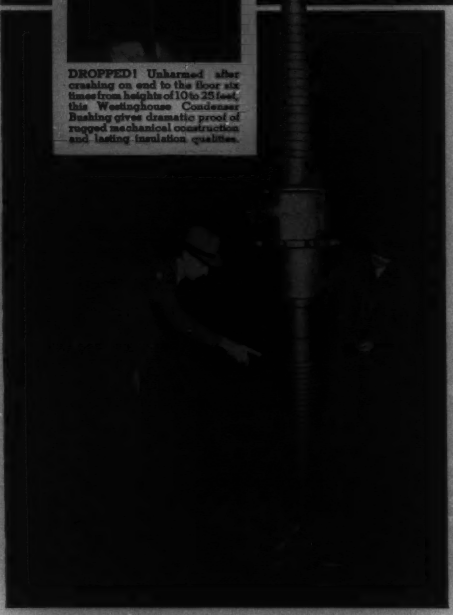

INTACT! Examination after six succeeding drops of 10 to 25 feet disclosed no damage. Standard commercial high potential and power factor insulation tests showed bushing electrically unaffected—air pressure test proved condenser intact and free from leakage.

EXTREME TESTS PROVE STRENGTH OF MODERN WESTINGHOUSE CONDENSER BUSHINGS

The most compact in size, paper-wound condenser type bushings are the strongest as well. Constant improvement in materials and processes, together with drastic tests have produced in today's Westinghouse Condenser Bushing a unit which defies moisture, extremes of temperature, and mechanical and electrical stresses.

Use of electrolytic copper foil now gives even greater adhesion between layers composing the condenser unit. The improved insulating compound between condenser and porcelain is non-hardening and is heavier than water. At lowest operating temperatures, perfect cohesion prevents voids, and adhesion to condenser and porcelain prevents moisture from reaching the condenser. New standardized cap for all bushings improves top seal, makes testing easier.

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CONDENSER BUSHINGS

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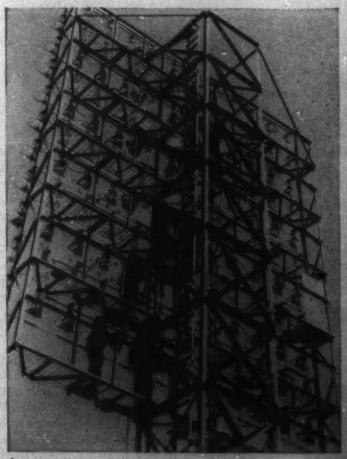
VERSATILITY in the design and erection of towers for floodlighting purposes, from the most simple of standard types to those which call for special consideration and unusual design, has always been a characteristic of American Bridge Company's tower service.

An outstanding installation is that recently made for the Pittsburgh Athletic Company, Forbes Field, Pittsburgh, where the towers are the backbone of a floodlighting system greater in magnitude than any heretofore developed for a baseball park. Clustered some 150 feet above the playing field of the Pittsburgh Pirates, 864 floodlights supported on eight American Bridge-built steel towers turn night into day.

Three of these galvanized towers, located in the outfield, rise the full 150 feet above their concrete foundations. The remaining five are supported by the existing structural steel roof frame of the grandstand, the trusses and columns of which were field-altered and reinforced to withstand the added strain. All eight were designed, fabricated and installed complete, even to the concrete foundations, by American Bridge Company.

However, many installations have much simpler requirements than those described above. For these our service is comparable in every respect. In addition, our Tower Department has developed a series of standard floodlight poles which are promptly available and unusually economical as to materials and installation. Why not refer your requirements to our nearest contracting office?



↑**CLOSE-UP VIEW** of a floodlight cluster. Eleven arms, each 26 feet long, cantilever on either side of the tower shaft to support 132 lights. Each level is framed with a maintenance platform and safety railings. An access ladder extends the full height of each tower.

ONE OF THE 150-FT. outfield floodlight towers carrying a cluster of 132 lights. Lights and electrical equipment were engineered by the Westinghouse Electric & Manufacturing Co. Tower base is protected by galvanized wire fencing manufactured and erected by Cyclone Fence Company, another subsidiary of the United States Steel Corporation. →

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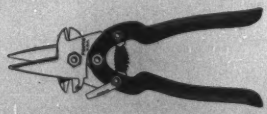
UNITED STATES STEEL

New Products

Resistance Standards.—These new resistance standards (series 800) are accurately calibrated resistances designed for d-c electrical measurements and a-c measurements at frequencies up to 20 kilocycles. All resistors are non-inductively wound on non-hygroscopic ceramic spools using manganin wire. The spools, where necessary, are mounted on heavy brass bars connected to binding posts highly insulated with Steatite. Surface leakage is not a factor in these standards, due to the extensive use of this effective insulation, according to the manufacturer, Shallcross Mfg. Co., Collingdale, Pa. Such standards are widely used for electrical measurements in research, engineering, teaching, and testing.

Combination Tool.—A new, compound action combination electrician's master cutter snip, wire cutter and splicer introduced by the Penn Tool Co., 2415 N. Howard St., Philadelphia, Pa., will cut metal up to 16 gauge, flexible pipe and tubing, wire, nails, etc. The tapered splicer will strip insulation from wire. The improved compound action requires less leverage for heavy duty work and eliminates the necessity of carrying various cutting tools on the job. The tool has a special locking device that will not interfere with cutting operations.



Automatic Reset Timers.—A new micrometer adjusting knob and indicator has been developed and is incorporated in the latest type of automatic reset timers and time delay relays manufactured by The R. W. Cramer Co., Inc., Centerbrook, Conn. The principal features of the new device are the simplicity, neatness of appearance, ruggedness of the mechanical assembly and the ease with which it permits accurate adjustment of the timer settings. A knurled knob which yields to a twist of the fingers drives a worm gear which in turn moves a pointer across the dial at a slow rate. Since the pointer is brought to a knife edge which travels across a scale of excellent visibility, very accurate settings can be made with little effort. The instruments can be easily reset to practically identical settings, and very minor changes in adjustment of the time interval are possible by a slight twist of the knob. These improvements bring within reach new limits of precision and accuracy since, once set, the timers and time relays repeat measurement of time interval within a few hundredths of a second.

Power Wire Wound Resistors.—A complete line of commercially noninductive power wire wound resistors, from 10 to 200 watts and with any type of mounting, has been introduced by the International Resistance Co., 427 N. Broad St., Philadelphia, Pa. These units utilize the Ayrton-Perry type of winding which, according to the manufacturer, assure full wattage ratings and eliminate differences in potential as well as high capacitances which may exist between adjacent turns on windings of other types. The degree to which inductance is reduced is well illustrated in the type DG 1,000-watt unit of 80 ohms resistances. With standard winding the inductance is 76 microhenries, whereas, with the Ayrton-Perry winding this is reduced to 0.3 microhenries.

Drafting Machine.—A new, completely adjustable ball-bearing drafting machine for drawings up to 24 by 36 inches has been introduced by L. G. Wright, Inc., 5209–20 Euclid Ave., Cleveland, Ohio, known as the "Wrigraph Industro Drafter". It can be clamped on to any drawing board up to 2 inches thick and 36 inches wide. A variety of extension clamps are available for mounting the machine on wider drawing boards. The machine has a hinged mounting, permitting it to be raised clear of the board. The protractor head is controlled with the left hand and a new design features a No-Set-Zero. A one-half degree vernier equipped with a magnifier provides for a quick and accurate setting of all angles. Standard Wrigraph transparent edge engine divided scales are available in all standard graduations.

Record Submarine Cable.—What is said to be the longest high voltage paper insulated submarine cable installation was recently completed, connecting the island of Martha's Vineyard to the steam power station of the New England Gas & Electric Association at New Bedford, Mass. The cable, 26,000 feet in length and rated at 24,000 volts, is of the triplex shielded, paper insulated leaded type, armored with BWG galvanized steel wires. The finished cable was 3.25 inches in diameter and weighed 14.50 pounds per foot. It was manufactured at the new Habirshaw plant of the Phelps-Dodge Copper Products Corp., Yonkers, N. Y. The conductor was made in five units of approximately one mile each and joined by heavily reinforced splices weighing about 600 pounds each. Due to the unusual conditions existing at Martha's Vineyard, the power company desired to lay the cable in one continuous length. This presented a number of problems to the manufacturer as well as to the purchaser since the weight of the cable and reel was about 460,000 lbs. It was decided to construct a reel 14 feet in diameter, with an 8-foot drum, divided into five sections on which the cable was wound and from which it was fed into the water from a steel barge 360 feet long. The cable was insulated in the manufacturer's new paper cable plant and given all electrical tests after the lead sheath was applied.

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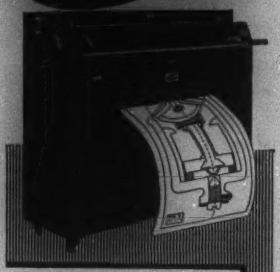

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Trade Literature

Magnetic Circuit Breakers.—Catalog 40, 36 pp. Describes magnetic circuit breakers, —time delay and instantaneous types, available in any rating between 50 milliamperes to 50 amperes. Heinemann Circuit Breaker Co., Trenton, N.J.

Transformers.—Bulletin B-6096, 16 pp. Describes distribution transformers, 1½ to 25-kva., 2,400 to 7,620 volts. The process of manufacture is profusely illustrated. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Extruded Tubing.—Bulletin. Describes a new, low cost extruded insulating tubing, type XTE-30; contains samples, gives sizes, specifies colors and lists prices. Irvington Varnish & Insulator Co., Irvington, N. J.

Air Circuit Breaker Switchgear.—Catalog 1230, 8 pp. Illustrates and describes low-voltage, metal-enclosed, air circuit-breaker switchgear available in both rigid and draw-out designs, and for both indoor and outdoor service. Roller-Smith Co., Bethlehem, Pa.

Capacitors.—Cat. 180X, 4 pp. Describes high voltage capacitors for heavy duty x-ray and impulse or surge-generator applications; especially suitable for use in technical research and university laboratories. Cornell-Dubilier Electric Corp., South Plainfield, N. J.

Whiteprint Machines.—Bulletin 187, 8 pp. Describes the new, model "F" fast printing whiteprint machine,—a printer-development combination which accommodates materials up to 42 inches wide, and has a maximum printing speed of 56 inches per minute. Ozalid Corp., Johnson City, N. Y.

Connectors.—Bulletin 6000, 16 pp. This booklet, "Electrical Connector Guide", consists of a series of charts which simplify the selection of the proper connector for any application. Procedure for making surveys of electrical connections, and other helpful data are included. Burndy Engineering Co. Inc., 459 E. 133rd St., New York, N. Y.

Recording Voltmeters.—Bulletin 543. Describes round-chart recording voltmeters and ammeters and their most common applications. Illustrates various models available for wall and flush panel mounting and for portable use. Bulletin 555 is devoted to portable instruments of the same type. The Bristol Co., Waterbury, Conn.

Cathode-Ray Tubes.—Cat. B. Describes cathode-ray tubes and laboratory equipment, such as 3-, 5-, and 9-inch oscillographs and the electronic switch, together with commercial television equipment including cameras, synchronizing signal generators, monitors and transmitters. Considerable practical data such as a discussion of cathode-ray oscillograph and tube characteristics and uses are included. Allen B. DuMont Labs., Inc., Passaic, N. J.

Electrical Equipment on S.S. "America".—Bulletin 4007, 16 pp. Describes electrical apparatus installed on the new liner, particularly control and protective equipment. Data on the ship's construction, operating details, large profile drawings of decks and hold and schematic arrangement of electric plant are included. I-T-E Circuit Breaker Co., 19th & Hamilton Sts., Philadelphia, Pa.

Bearings.—Catalog 40, 64 pp. Describes and lists with complete specifications and prices, hundreds of stock sizes of cast bronze, sleeve type, standardized bearings—industrial, electric motor, graphited oil-less; precision bronze bars and babbitt metals. The Bunting Brass & Bronze Co., Toledo, Ohio.

Test Kits.—Bulletin 2815. Describes a portable testing outfit consisting of ammeter, voltmeter and current transformer. Originally devised for survey purposes, these kits have found wide application in industrial plants. Various combinations are available. Herman H. Sticht & Co., 27 Park Place, New York, N. Y.

Laboratories Offer Services to Government.—An 8-page booklet issued by the Electrical Testing Laboratories, Inc., East End Ave. & 79th St., New York, N. Y., presents the advantages of the utilization by the government of the facilities of independent commercial laboratories in connection with procurement for national purposes. The obstacles to the employment of such laboratories under present rulings are outlined.

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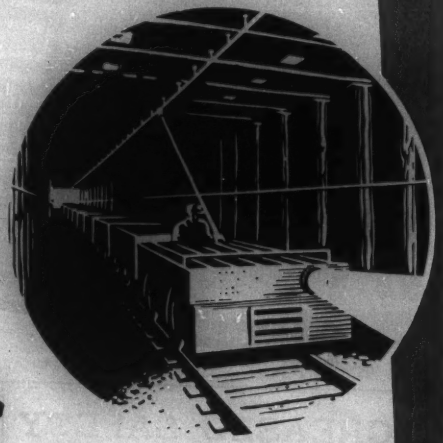

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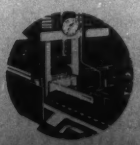

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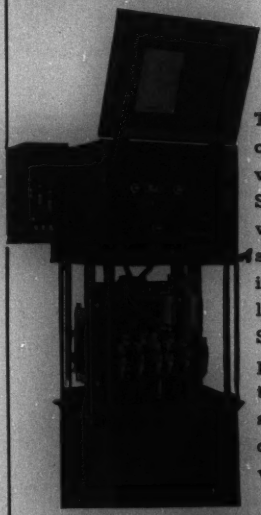

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B.S. E.E., 1935, Kansas Univ; 28, married. 2½ yrs elec draftg exper on generating and substations; service engr on air conditioning controls; structural draftg. Available immed. E-694.

E.E., M.E.; married; 27 yrs des, constr pwr houses, substations, distr systems indus plants, exec engg dept large util; purchased engg eqpt foreign interest. English, German, Russian and Oriental languages. E-695.

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B.S. E.E., 1930. Util engg, indus engg and constr, mining electrification and electrician. Interested in connection util, indus organization or mining co. Available short notice. Free to travel. E-697.

GRAD E.E., 1926; 36, single; 19 mos General Elec Test Course; 10 yrs steam and diesel pwr plant oprn, indus maintenance, motor rewind, constr, some pub util exper. Speak Spanish. E-698.

ELEC ENGR, Fellow AIEE; exper in management of ceramic and light mfg; des and constr of high voltage stations and special purpose machines and processes; successful as sales engr. E-699.

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E.E., Fellow AIEE, NY license, supervision of constr pwr plants, dams, concrete work, transm lines; maintenance; pub util reports and valuations; consulting exper. 9½ yrs in So. Am. E-702.

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E.E. Carnegie Tech 1932, Reg Engr W. Va.; 5 yrs elec problems coal mines (purchase to consumption) with consulting engg firm. Knowledge higher accountancy. Exper highway surveying. Now studying Spanish. E-705.

B.E.E., O.S.U., 1935; single, 29; now employed; 4 yrs conveyor engg draftg, des. Devpmt work desires. Pleasing personality, good organizer. M.W. preferred. E-706.

PLANT ENGR, E.E., 1922; 16 yrs indus plant constr, oprn, des, devpmt. N.J. Grade A oprtg license; now employed, desires application or constr pos with increased opportunities. Foreign language, German. E-707.

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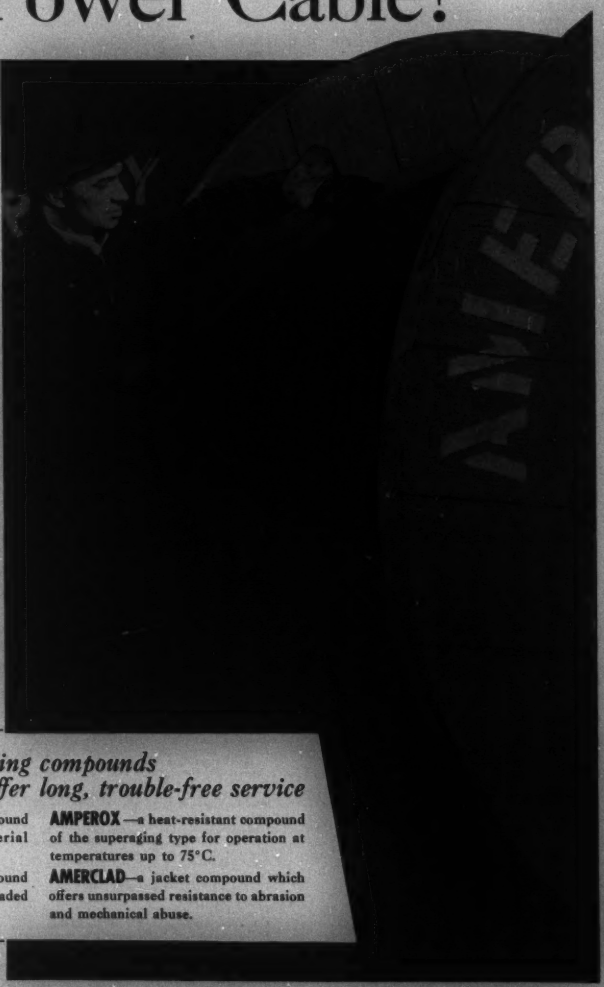
That's 31 years of immersion in water and mud, of direct burial of shore ends in acid and alkaline soils, and of exposure of pole risers to extremes of heat and cold—the same conditions, in exaggerated degree, that are found in many less exacting applications.

Here is real proof that American Steel & Wire Company knows how to engineer and manufacture cables for long, trouble-free service.



These rubber insulating compounds offer long, trouble-free service

AMERITE—a 30% Class AO compound for general underground or aerial service.

AMARINE—a 40% rubber compound recommended especially for non-leaded submarine service.

AMPEROX—a heat-resistant compound of the superaging type for operation at temperatures up to 75°C.

AMERCLAD—a jacket compound which offers unsurpassed resistance to abrasion and mechanical abuse.

AMERICAN STEEL & WIRE COMPANY

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors*

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UNITED STATES STEEL

Advertised Products Index

AMMETER COMPENSATING COILS
Minerallac Electric Co., Chicago

AMMETERS, VOLTMETERS
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BEARINGS, BALL & ROLLER
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Tree Wire
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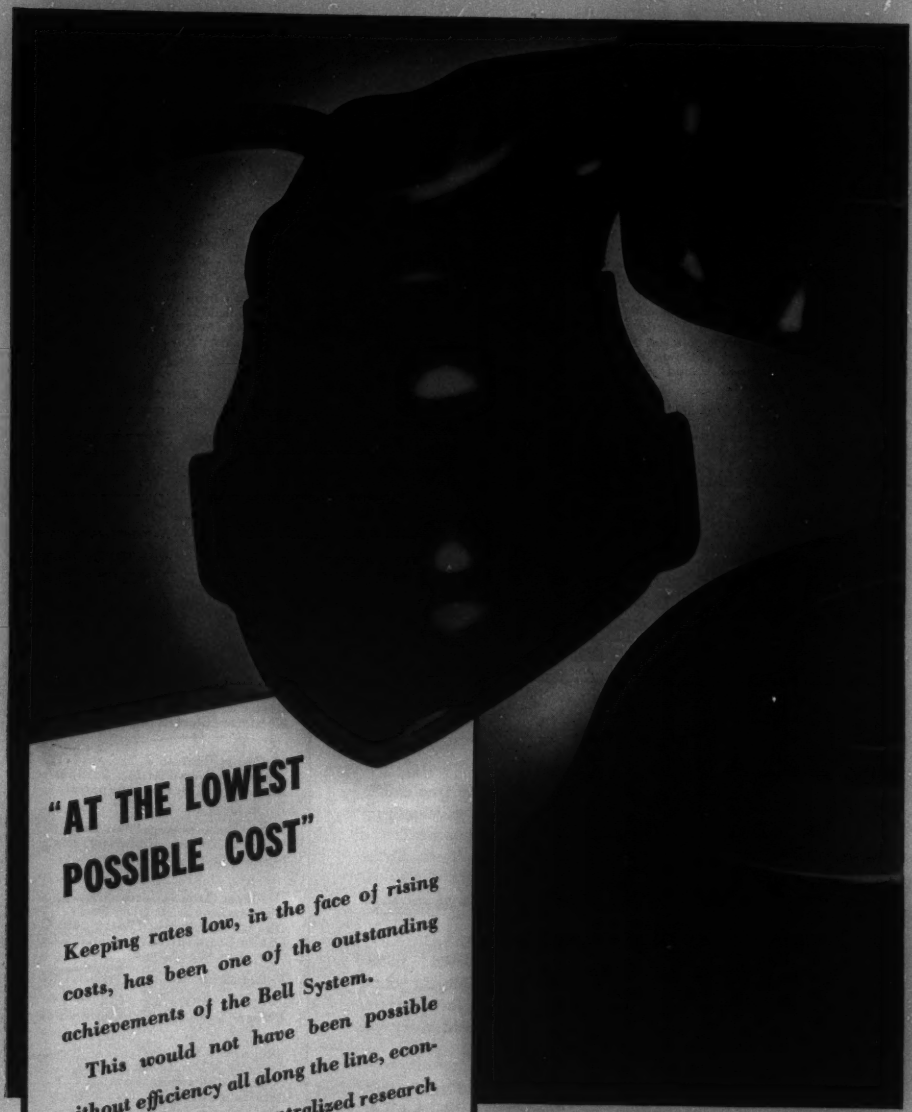


"AT THE LOWEST POSSIBLE COST"

Keeping rates low, in the face of rising costs, has been one of the outstanding achievements of the Bell System.

This would not have been possible without efficiency all along the line, economies resulting from centralized research and manufacture, and a sincere desire to serve the best interests of the public.

BELL TELEPHONE SYSTEM

900,000 Guy Hook Installations—Why?

Why have Electric Light and Power Companies, constituting over half the operating capacity of the U. S. and Canada, placed this M. I. F. line of Through-bolt Guy Hooks on their approved lists? The result has been 900,000 installations in a little over four years, and this is why—or so we are told:

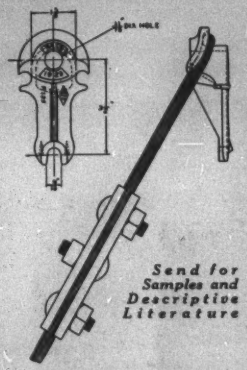
1. Simplification of Guying Specifications results from the use of M.I.F. Through-bolt Guy Hooks as they are used with stock through-bolts and lags.

2. Economical construction results as the patented M. I. F. Guy Hook is cheaper than other acceptable through-bolt guying devices developing equal performance under test. Accessory Curved Ribbed Washers, Eye Nuts, Bolt Eyes, and High-strength Thimbleless Eye Anchor Rods are all competitively priced, or better. The durability of these galvanized malleable castings is beyond question.

3. Safe construction results from using M. I. F. Guy Hooks. As the guy loop is made up on the ground and then carried up the pole and placed over the Guy Hook retaining ear, protection from contacting live wires is more readily assured. There are no records of failures in service.

4. Proper through-bolt guying leads to no regrets. At least 95% of all sales of 100 or more M. I. F. Guy Hooks have led to consistent repeat orders.

To Transmission and Distribution Engineers, not now using these M.I.F. Guy Hooks and Accessory Through-bolt Guying Devices, we extend an invitation to write for samples *without obligation.*



Misc. M.I.F. Pole Hardware Specialties:—*Williams Pole Mounts—Pole Stubbing Clamps—Aerial Cable Messenger Clamps and Insulated Hangers—Malleable Secondary Racks and Clevises—Tubular Pole Fittings—Transformer Hanger Plates for Through-bolt Mounting—Malleable Crossarm Gains—Screw Anchors—Sidewalk Guy Fixtures and Alley Arm Braces—Crossarm Braces—Guy Strand Payout Reels—Through-bolts, etc.*

MALLEABLE IRON FITTINGS COMPANY

Pole Hardware Dept. [Factory and New England Sales Office] Branford, Connecticut

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NOISE MEASUREMENT

In determining the true causes of observed sound levels and in measuring the levels produced by apparatus, the "Test Code for Apparatus Noise Measurement" will be found of great value in establishing uniform methods of conducting and reporting such tests.

The following subjects are covered: radiation of sound, room effects, ambient sound levels, instruments standards, factory tests, measurement positions and field investigations.

This Test Code was developed by the Subcommittee on Sound of the A.I.E.E. Standards Committee and was published in 1939. Copies are obtainable at a cost of 30 cents each (50 % discount to A.I.E.E members on single copies).

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

33 West 39th St. New York, N. Y.

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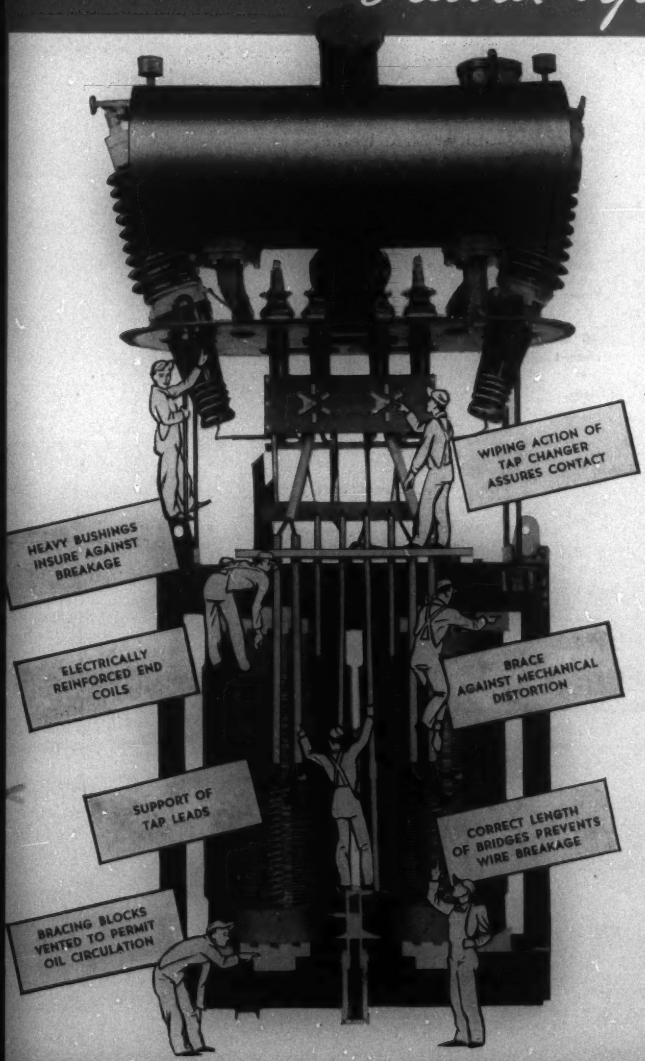
7 reasons why...

KUHLMAN POWER TRANSFORMERS

Stand up on the job


HEAVY BUSHINGS INSURE AGAINST BREAKAGE
WIPING ACTION OF TAP CHANGER ASSURES CONTACT
ELECTRICALLY REINFORCED END COILS
BRACE AGAINST MECHANICAL DISTORTION
SUPPORT OF TAP LEADS
CORRECT LENGTH OF BRIDGES PREVENTS WIRE BREAKAGE
BRACING BLOCKS VENTED TO PERMIT OIL CIRCULATION

As every electrical engineer knows, the mechanical construction of a large power transformer has a vital bearing on its all-around life and efficiency. For that reason Kuhlman Power Transformers are designed and built to safely withstand the stress and strain that goes hand-in-hand with heavy loads.

Cores and coils are effectively braced against mechanical distortion. Long bridges prevent wire breakage due to vibration. End-coils are reinforced to prevent failure from surge potentials. Tap changers and tap leads, frame and case, are all ruggedly built. In fact each component part of these sturdy power transformers is of extra-heavy construction.

The little men (left) graphically illustrate seven of the many reasons why Kuhlman Power Transformers stand up on the job. And records of hundreds of installations offer convincing proof that because of their construction, Kuhlmans give day after day service with a minimum of maintenance.

KUHLMAN ☆ ELECTRIC COMPANY

230,000 POUNDS of ARMOR-CLAD INSURANCE

...for an area VITAL to our DEFENSE PRODUCTION

Cross Section Actual Size

This Okolite-insulated non-leaded submarine cable, weight 20 lbs. per foot and nearly 15 inches in circumference, was recently delivered to a major power company* on an order placed in anticipation of the vital need for unfailing power in one of the nation's key industrial areas in the National Defense Program.

Okolite insulation, resistant to moisture and ozone, was selected because it requires no lead sheath. This eliminates the possibility of lead trouble and, in the event of mechanical injury to cable, will lessen time needed for making repairs and getting this important cable back into service.

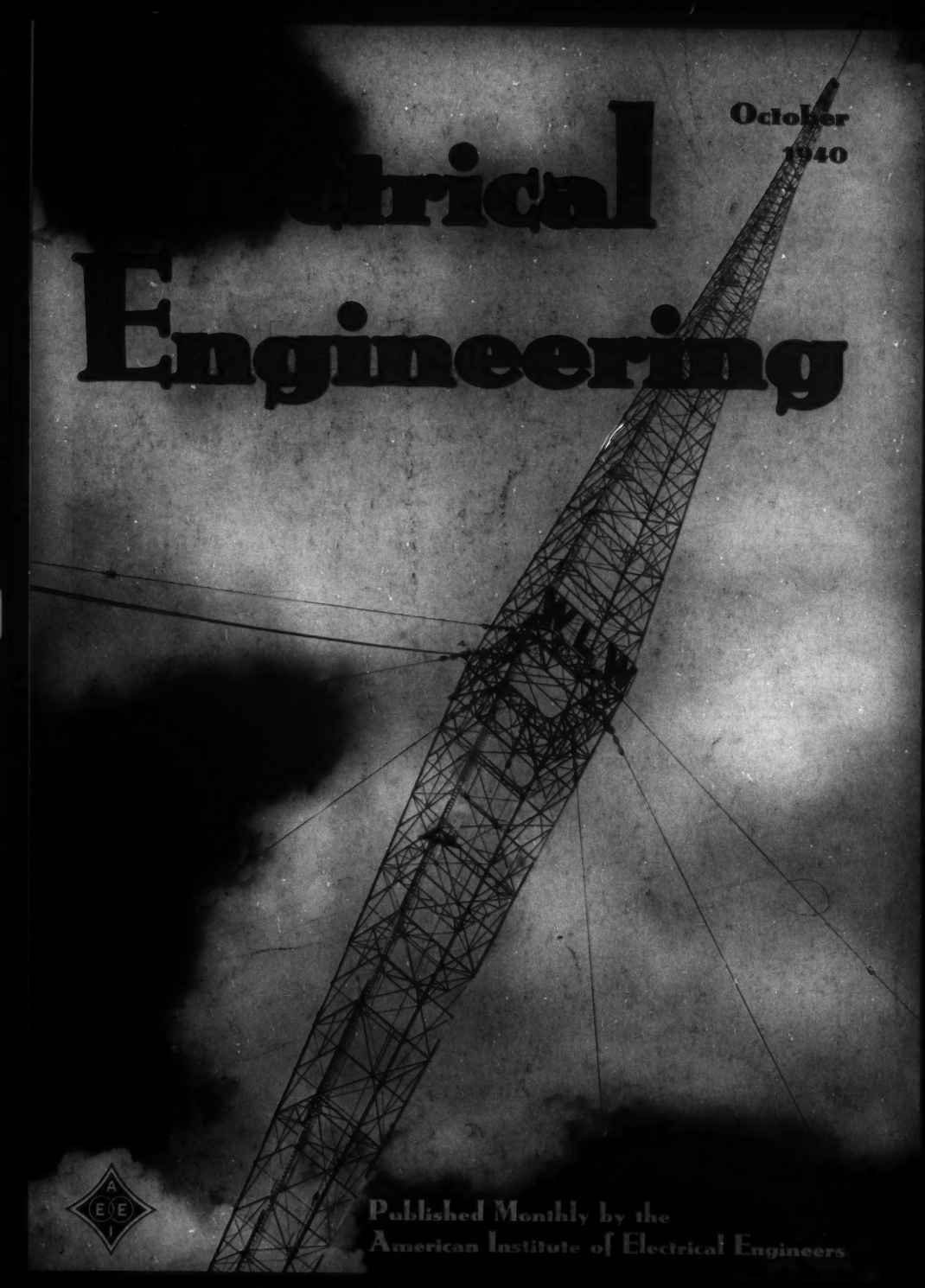
Whether you need cable by the carload or the coil, it will be worth your while to consult with Okonite Engineering Service before you make your next cable purchase. The Okonite Company, Passaic, N. J., offices in principal cities.

*Name on request

This 22,000 volt rubber-insulated cable required the following material for its fabrication:

Copper (26½ tons) — 500,000 CM conductors (Okoloy-coated to prevent corrosion).
Insulation (16½ tons) — 28/64" Okolite insulation, resistant to moisture and ozone.
Shielding Tape (3 tons) — .005" Type K. Monel (non-magnetic and corrosion-resisting).
Saturated Jute (8½ tons) — for filling interstices and cushioning armor wires.
Armor Wire (51½ tons) — No. 4 B.W.G. galvanized steel for mechanical protection.
Miscellaneous Materials (7½ tons) — asphalts, tapes, saturants, etc.

OKONITE
INSULATED WIRES & CABLES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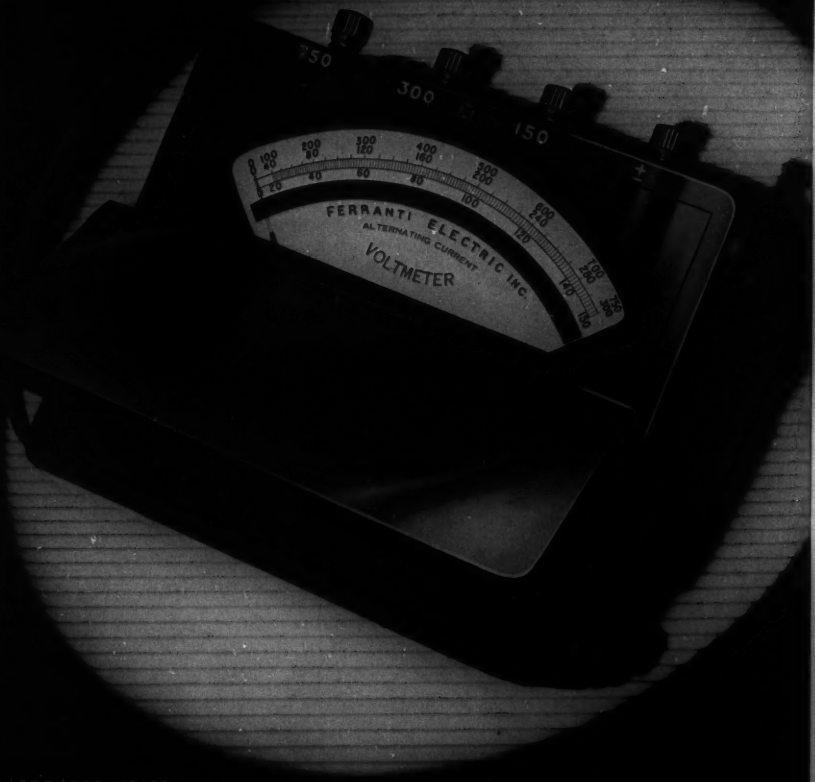
New PORTABLE VOLTMETER

HIGHER ACCURACY • LONGER SCALE • LOWER COST



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Accurate to ½ of 1% • Easily-read Hand-calibrated Mirror Scale, 5¼ long, with 150 divisions • High Torque-weight ratio • Magnetically shielded • Exceptionally well damped • Self-contained in compact dust and damp-proof case, with hinged cover and leather carrying handle • This new precision voltmeter offers outstanding value to all engineers interested in accurate measurements.

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FOR CONSTRUCTION OR REPAIR OF

Coils OR *Motors* LARGE OR SMALL

USE **SCOTCH** *Electrical* **TAPE**

Scotch Electrical Tapes are pressure sensitive and are applied without moistening. They have high dielectric strength and suitable insulation properties. Available in a variety of backings and adhesives for the numerous holding, insulating or protecting applications.

Why not try a sample roll on your present work.

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Gentlemen: Kindly send sample roll of tape for the following purpose_____
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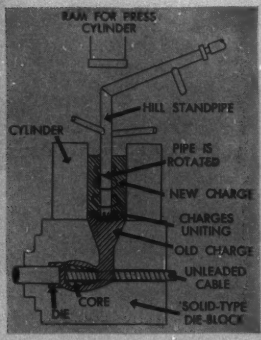
OKONITE-CALLENDER Sets the Pace

with 5 of Improved

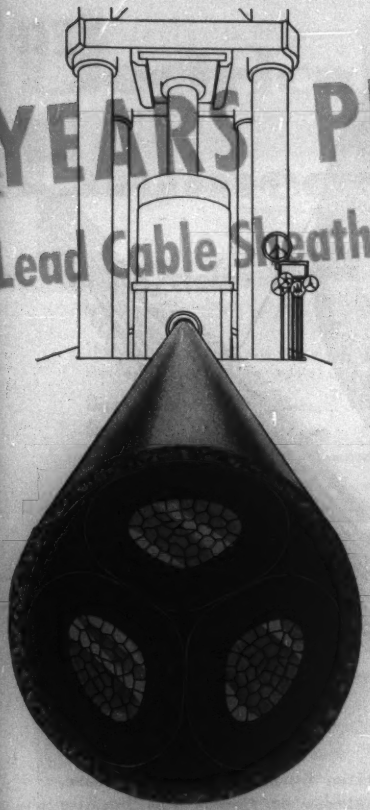


The Hill Standpipe in use (left). Operator fills press with molten lead through a rotated pipe extending down to surface of old charge. The diagram above shows how hot lead delivered at this point melts slug remaining in press and mixes with it. Any oxide on the surface of the old charge floats to the upper surface of the molten metal where it is removed, leaving the old and new charges united in a perfect weld.

OKONITE-

YEARS' PRODUCTION

Lead Cable Sheaths — Without Flow Lines!



Okonite-Callender Paper Cables, sheathed with lead free from partings, flow lines, occluded or dissolved gases, oxides, sulfides and other foreign matter.

THE HILL STANDPIPE METHOD of charging a lead press was made our standard factory procedure 5 years ago and completely described at the A.I.E.E. Pacific Coast Convention in June of last year. Results achieved by its use have conclusively proved the value of the bottom-filling technique (see diagram). The oxide film on the top of the old charge is eliminated, thus assuring complete welding of successive press charges. Sheaths produced by this method are free from laminations and flow lines throughout the length of the cable.

Additional benefits can be obtained when the lead used for sheaths is stabilized by the sodium process (another Okonite-Callender Research Development made standard factory practice three years ago). This eliminates oxide and sulfide inclusions from the *original* lead and reduces their formation to a minimum during the charging operation—not only on the surface but also throughout the entire mass of the press charge. This results in higher sheath strength and greater corrosion resistance.

Full particulars of these methods used in sheathing Okonite-Callender Paper Cables are contained in our Booklet OK-1004 which also includes a reprint of the A.I.E.E. paper by Wiseman and Reinitz. The Okonite-Callender Cable Co., Inc., Executive Office, Passaic, N. J. Offices in principal cities.

IMPORTANT FACTS ABOUT THE STANDPIPE METHOD OF FILLING LEAD PRESSES

1. The Standpipe method of filling press cylinders results in better lead sheaths for the reasons explained on these pages.
2. The original filling device (the Hill Standpipe) was developed nearly 10 years ago by our associate—Callender's Cable and Construction Co., Ltd., of England — and introduced by Okonite-Callender into this country.
3. The principles of the method — as described in U. S. Patent, 1,981,045 — are:
   a. "melting the surface of the old charge to produce a homogeneous joint between the old and new charges which consists in causing a stream of molten metal . . . to impinge upon . . . the old charge . . . so as to melt the latter to a substantial depth."
   b. "introducing molten metal . . . downwardly and laterally."
4. The Hill Standpipe technique has been used in Okonite-Callender's regular factory production since August 1935 — which means that purchasers of Okonite-Callender cables have been getting the benefits of better lead sheaths for over 5 years.

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● Synonyms, when speaking of O-B bushings, for "porcelain-filled" does mean long life and freedom from care. O-B bushings are literally full of porcelain, and that explains why they perform satisfactorily for so many years and require virtually no maintenance. Being inorganic, porcelain is not affected by moisture, temperature, electrical stress or *time*. And because porcelain is used for the internal concentric barriers, O-B bushings are not subject to puncture or to progressive surface breakdown from current leakage. O-B units also have the full compression assembly, butt-type joints, free oil circulation, differential expansion and contraction provisions, and proper ground shielding. To get *all* of these money-saving features—just specify "Bushings by O-B" when buying apparatus.

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